A VOYAGE IN SPACE

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A VOYAGE IN SPACE

[*Frontispiece*

ICAROMENIPPUS

(See Notes to Illustrations)

A
VOYAGE IN SPACE

A COURSE OF SIX LECTURES "ADAPTED TO A JUVENILE AUDITORY" DELIVERED AT THE ROYAL INSTITUTION AT XMAS 1913

BY

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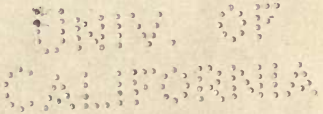

WITH OVER 130 ILLUSTRATIONS

SOCIETY FOR PROMOTING CHRISTIAN KNOWLEDGE
LONDON: NORTHUMBERLAND AVENUE, W.C.
1915

BY THE SAME AUTHOR

MODERN ASTRONOMY

Constable & Co., 1901. Price 2*s.* 6*d.*

ASTRONOMICAL DISCOVERY

Edward Arnold, 1904. Price 10*s.* 6*d.*

THE GREAT STAR MAP

John Murray, 1912. Price 2*s.* 6*d.*

TO

MY MOTHER'S GRANDCHILDREN

342311

PREFACE

THESE lectures, delivered at the Royal Institution at Christmas 1913, as the eighty-eighth course of Juvenile Lectures, were taken down at the time by a shorthand writer. When I entered on the revision for publication, my first intention was to abandon the language of the lecture-room, substituting a narrative form. But I found the translation attended by all sorts of difficulties, so that the task assumed somewhat alarming dimensions. At this point I happened to look again at Faraday's *Chemical History of a Candle*, and saw that he had not thought it necessary to depart from the lecturing mode : with great relief I therefore ventured to follow him in this matter.

There are passages where I will ask the indulgent reader to remember that many of my audience were of very tender years : there are others where he will perhaps kindly allow his thoughts to dwell on the parents who came with them. If the alternation of view-point is somewhat erratic at times, I trust he will make some allowance for the difficulties.

Very few alterations of importance have been made, although the two years which have slipped away between the giving of the lectures and the passing of the final proof-sheets have added their due share to astronomical history. It seemed desirable to note the discovery of a ninth Satellite to

Jupiter, by Mr. S. B. Nicholson, in the table on p. 180 and on p. 181; but footnotes have been used for this addition, in order to keep the text nearer the original date. Possibly I have overlooked something in dealing with similar recent discoveries: Astronomy moves fast in these days, and it is not easy to keep the pace she sets.

The hypothesis of a Sunspot-swarm of meteors, given on pp. 200–206, has been added intentionally. At the time of the lectures it had only just been formulated, and although the picture on p. 205 was shown, little was said on the matter. Two years' consideration has strengthened my confidence in this interpretation of the facts known to us, without producing any objections of a fatal character; and it seemed to me therefore that, as I was writing a book, I ought to put it in; to omit it might be interpreted as a lack of confidence on my part. At the same time I do not wish to ignore the attitude of other astronomers, which is duly acknowledged on p. 205.

I have made every effort to acknowledge the source of the illustrations and to obtain permission for their publication where needful. But there may be some oversights. If so, I would beg the same kind consideration for the lecturer turned author as is extended to him from all quarters during his preparation of the lectures, immediately he mentions the magic words "Royal Institution" and "Children's Lectures."

H. H. T.

University Observatory,
Oxford:
November 10, 1915.

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NOTES TO ILLUSTRATIONS

Cover of Book

On the back is the great Tower Telescope of the Mount Wilson Observatory, California, to which reference is made on p. 122.

On the panel is the representation of the billiard-ball experiment on p. 286. The experiment was made by some of the children in the audience, and the author asked one of them to make a picture of it for the book. Without any suggestion from him, she chose to idealize it, introducing some of the zodiacal signs as agents; and seeing that the notion to be illustrated is that of the falling together of stars from different quarters of the heavens, the picturesque change is specially appropriate. Altogether it was felt that no other illustration was so representative of the voyages of the heavenly bodies; and to choose it for the cover was therefore natural.

ICAROMENIPPUS (*Frontispiece*)

While these lectures were being prepared for publication, the author was privileged to admire various drawings by "Alice (aged 13)" contributed to a magazine of original drawings which makes periodical but rather mysterious appearances in Oxford. It seemed to him that a picture of Icaromenippus, designed by an artist of an age representative of the important part of his audience, would be a welcome addition to this volume. The application was kindly received and in a few weeks' time no less than nine quite different designs were sent, any one of which would meet requirements. The choice was difficult, but skilled assistance indicated the one here reproduced.

A comment on the eternal divergence between Art and Science is suggested. The mere astronomer will no doubt point out that the crescent moon is not limited by its illumination, but is part of a large globe which

would make the position of Icaromenippus impossible. But artists have so often and so persistently claimed the right to ignore this fact that it would be discourteous to maintain this objection.

PAGES 15 and 16.—The pictures of Tycho Brahe's observatory and sextant are from the beautiful collections made by Professor Weinek of Prague, and published in the observatory volumes.

PAGE 19.—The Earth and Halley's Comet. This drawing originally appeared in the *Illustrated London News* for Sept. 25, 1909, and is reproduced by kind permission.

PAGE 36.—The Great Comet of 1858 is from *Telescope Teachings* by the Hon. Mrs. Ward (Groombridge & Sons, 1859), a book with numerous beautiful illustrations much prized by our fathers and grandfathers.

PAGE 39.—The Return of Halley to see his Comet is, as stated in the text, from a picture in the possession of Mr. H. P. Hollis, of the Royal Observatory, Greenwich, and is reproduced by his kind permission.

PAGE 42.—Changes in a Comet's tail by E. E. Barnard. This is not the pair of pictures shown on the screen at the lectures, but is a triumph of Professor Barnard's skill given in the *Astrophysical Journal*, Vol. XXII., Plate VIII. (facing p. 251).

PAGE 48.—Wreck of the Searchlight apparatus. This illustration is from p. 380 of *Pearson's Magazine*, in the volume July–December, 1907; and is reproduced by kind permission of the Editorial Manager. The author is fortunate enough to possess the original pair of drawings for this excellent story.

PAGES 60 and 61.—Transit of Venus. These illustrations are reproduced (by permission of the Delegates of the Clarendon Press) from Chambers's *Handbook of Astronomy*.

PAGE 63.—Horrox observing the Transit of Venus. This is reproduced, by kind permission of Mr. Napier Clark, formerly of Southport and now of 16 Hallhead Road, Edinburgh, from a picture in his possession painted by W. R. Lavender. There is no description or portrait of Horrox in existence, and the representation is therefore purely imaginary. The observation was made at the village of Much Hoole, near Southport, on Nov. 24 [o.s.], 1639. Horrox was at that time about twenty. The

picture has been painted with careful attention to all that is known, or can be conjectured, of the circumstances.

PAGE 84.—Appley Bridge Aerolite. Reproduced by kind permission of the Royal Astronomical Society from *Monthly Notices*, Vol. LXXV. p. 94. The aerolite fell on Oct. 13, 1914 (after the lectures were given). Its length was 9.65 in., depth 9.13, and width 6.62 ins. It ranks as the second largest recorded fall in Great Britain.

PAGE 93.—W. Herschel's 20-foot telescope. My thanks are due to the Herschel family for permission to reproduce this illustration. It appears as Plate B in Vol. I. of the recently published *Collected Papers*, and is described as "from a Drawing made either at Datchet or at Clay Hall."

PAGE 97.—"The Great Five-foot being taken up Mount Wilson," and p. 98, "An Accident to the Traffic up Mount Wilson," are due to the courtesy of Professor Hale. The latter represents the only serious accident attending the whole of the extended series of transport operations. Two of the men jumped from the car as it was slipping over the track, but the driver stuck to his car and went down with it. Mr. Adams, dashing down the steep incline, found him badly cut and bruised; but with ropes he was hauled up and taken to hospital.

PAGE 114.—Great Nebula in Andromeda. This picture is taken by kind permission of the Royal Astronomical Society from No. 98 of their series. It is from a photograph taken by G. W. Ritchey and F. G. Pease at the Yerkes Observatory on Sept. 18, 1901, with a colour screen on the 40-in. refractor.

PAGE 116.—*Victoria Telescope*. This record of an incident of the erection of the telescope I owe to the kindness of the late Sir David Gill.

PAGE 119.—A coelostat at Oxford. The coelostat was invented many years ago by a Frenchman named August. It was, however, not much used. In 1896 Dr. Johnstone Stoney directed attention to a paper by the great French physicist Lippmann, in which he recalled the principle. It was at once seen that the instrument was specially suitable for eclipse work, and a pair of coelostats were constructed under the direction of Dr. Common for the 1896 eclipse. The picture shows one of these being mounted in the garden of the University Observatory at Oxford, in order to test

its performance before starting for Japan to observe the eclipse.

PAGE 120.—The Snow Horizontal Telescope, and p. 122, The High " Tower " Telescope, are from Professor Hale's *Annual Reports*. One sometimes feels that more than a perfunctory word of thanks is due to the astronomers of the Harvard, Lick, Yerkes, Mount Wilson and other great American observatories for the plentiful supply of beautiful pictures to the world at large.

PAGE 124.—The ascent in the bucket is from a snap-shot taken during the visit of the Solar Union to Mount Wilson in 1910, and kindly sent to me by one of the occupants of the " elevator."

PAGE 127.—The cities of Pasadena and Los Angeles, from a beautiful print kindly sent me from Mount Wilson the particulars of which have unfortunately been mislaid.

PAGE 133. — Algol, " An Astronomical Reprobate." This illustration is reproduced by the special permission of the Proprietors of *Punch*. It is from the number for Jan. 18, 1899. The note under the drawing is as follows: " The star Algol behaved in a most ill-bred manner. He would advance, wink, and then retire. For years his motion and behaviour puzzled astronomers, until at last the mystery was solved by Professor Vogel, who showed that Algol had associated with him a dark star, which was invisible, and that the latter sometimes obscured the former. Algol and his invisible playmate revolved round each other, and this accounted for the fact that Algol seemed to us to wink."—*Sir Robert Ball's Lecture at the Royal Institution*.

PAGE 138.—Mars, as drawn by N. E. Green, is taken by kind permission of the Royal Astronomical Society from Plate II., Fig. 11, of their *Memoirs*, Vol. XLIV. It was made by use of a 13-in. reflector by Geo. With, and is dated Sept. 10, 1877, 11 hrs. 20 min; longitude 297°. The original is beautifully tinted, but it has not been possible to reproduce the tinting here.

PAGE 145.—Mars, with the 40-in. from a print kindly sent me by Professor Barnard. His note on the back is " 40-in. direct enlargement, Sept. 28, 1909."

PAGE 147.—Jupiter, by Mr. Scriven Bolton. This pair of drawings was kindly made specially for this book. The original is a chalk drawing in which Jupiter's equatorial

diameter is 6 in. The date of the observations is Dec. 4, 1906, and the interval between the sketches is 1½ hours.

PAGE 151.—Saturn. The three photographs are from a longer series kindly sent me by Professor E. E. Barnard, taken by him with the 60-in. reflector on Mount Wilson (Cal.), Nov. 19, 1911.

PAGE 163.—Leverrier Statue. From the memorial volume to Leverrier, published by the Institut de France, on the centenary of his birth (March 12, 1811). The statue by Chapu was erected in 1889 in the Cour du Nord of the Paris Observatory.

PAGE 164.—Plaque of Adams is reproduced from a photograph taken in Westminster Abbey by Mr. Wright.

PAGE 185.—By kind permission of the publisher, Mr. John Murray.

PAGE 189.—Liquid Air Experiment. Reproduced from the *Illustrated London News* of Jan. 10, 1914, by kind permission of the Editor.

PAGE 195.—Sun as taken at Greenwich. One of a series kindly supplied for lecture purposes by the Astronomer Royal.

PAGE 205.—Collision of Saturn and Leonids. Reproduced from the *Illustrated London News* of Dec. 20, 1913, by kind permission of the Editor.

PAGE 212.—Drawing by Huggins. Reproduced by kind permission of the Royal Astronomical Society from *Monthly Notices*, Vol. XXVI., p. 263.

PAGE 213.—Drawing by Nasmyth. The original drawing was presented by the artist to the Oxford University Observatory, where it now hangs.

PAGE 215.—Hansky's photographs, from *Mitteilungen der Nikolai-Hauptsternwarte zu Pulkowo*, Band, I. No. 6.

PAGE 218 and 220.—Figs. 62, 63 and 65–70 are again due to the courtesy of Professor Hale. They may be found in the *Astrophysical Journal*, Vol. XIX. and Vol. XXVIII.

PAGE 237.—The Japanese eclipse. The 1896 expeditions, for which the coelostats were prepared (see note above to p. 119), went one to Norway and one to Japan; but both had cloudy weather at the critical moment. A Japanese artist accompanied the latter expedition from Tokio to its observing station, and was to have painted

the Corona, which never appeared. During the time of preparation, however, he made several sketches of the instruments.

PAGE 251.—The Southern Cross. From a photograph taken with a 6-in. lens at the Sydney Observatory, on August 13, 1890. Exposure three hours.

PAGE 255.—The split nebula in Andromeda is from a photograph taken by W. S. Franks.

PAGE 256.—The Nebula in Cygnus is from a photograph kindly presented to the Observatory by the late Dr. Isaac Roberts. Exposed Oct. 27, 1896, for 2 hrs. 18 min.

PAGE 259.—The star cluster in Hercules (M 13), from G. W. Ritchey's beautiful photograph taken with the 40-in. Yerkes refractor, with a colour screen.

PAGE 273.—The coloured plate of spectra is the plate arranged by Professor Newall for his book on the Spectroscope. At the suggestion of the publishers, and with Professor Newall's kind permission, it is adopted here, to save the preparation of a special plate.

PAGE 281.—The flight of ducks. From the close resemblance of this picture to Fig. 91, representing star movements, it might be supposed that it was designed to fit. But the resemblance is purely accidental. Wandering one day among Mr. Newton's stacks of beautiful lantern slides, my eye fell on this picture, and I purchased it to illustrate stellar migrations, without realizing at the moment how closely it fitted the Taurus cluster. It is from a series which appeared originally in the *Illustrated London News*, and is reproduced by kind permission.

PAGE 286.—The billiard ball experiment. See note above on the illustrations for the cover.

PAGE 297.—The expanding nebula round Nova Persei is from the photographs by G. W. Ritchey, taken with the two-foot reflector of the Yerkes Observatory. See *Astrophysical Journal*, Vol. XIV. p. 293.

UNIV. OF CALIFORNIA

A VOYAGE IN SPACE

LECTURE I

THE STARTING-POINT, OUR EARTH

THE idea of a "Voyage in Space" is not new by any means. Two thousand years ago it occurred to the Greek writer Lucian to suppose a man flying up to the heavens. He called him Icaro-menippus, because Icarus was supposed to have been the first man to fly. In one of the old stories which were told to Greek children (just as stories are still told to children even in our twentieth century), it was related how Daedalus, the father of Icarus, made him some beautiful wings; but they were only fastened on with wax, and when Icarus flew near the Sun, the wax melted and he fell. Lucian's Icaromenippus was wiser. He caught a large eagle and a large vulture; and then he relates how

> [I] cut off very carefully the right wing of the eagle and the left of the vulture, then tied them on, securing them over the shoulder by strong straps, and at the ends of the quill feathers I put in things like loops for my hands to grip.[1]

[1] *Six Dialogues of Lucian*, by S. T. Irwin. Methuen & Co., 1894.

He practised flying, gently at first, and then more boldly, until he flew up to the Moon, and looked down on the Earth (*see* Frontispiece), which he declared was much smaller than the Moon. One of the striking points in Lucian's tale is the suggestion that the eagle's wing endowed Icaromenippus with the eagle's sight.

> An eagle has the keenest sight of any living thing, and the eagle alone looks straight at the Sun.

And so he was able to see things happening on the distant Earth.

Nowadays, of course, we should bring a telescope into the story; but the telescope was not invented until more than a thousand years after Lucian's time, and the best he could think of was this vague notion of the eagle's " strong sight," which in some mysterious way helped Icaromenippus to see very distant things. But since he had not the magnifying power of a telescope the distant things looked very small. He tells how our earthly cities, " including the inhabitants, were not at all unlike ant-hills." It is good for us sometimes to remember how small we are compared with the universe, or even with the solar system of which our Earth is a rather unimportant member : and it is noteworthy that in this early example of a pretended " Voyage in Space " Lucian does not forget to make this use of it.

Since his day many others have had the same notion of pretending to get away from the Earth, and to visit one or other of the planets.

In my boyhood we read a book by Jules Verne,

in which a projectile carrying three men is supposed to be shot from an enormous cannon towards the Moon. The pictures were fascinating, and it is distressing to find that the edition with the pictures seems to be out of print; at any rate, I have not been able to recover a copy, though I much wanted to reproduce some of the pictures for you on the screen. There was a terrible explosion when the cannon was fired, and how those poor men ever survived the shock is a mystery which only great writers like Jules Verne can understand. But they did survive, and had most wonderful adventures. They even had the complacency to go over their calculations again, while inside their projectile, travelling at a furious speed towards the Moon; and found that they had made a mistake! It was rather late to find it out, wasn't it? after they had started all wrong. It is better to go over such calculations twice *before* one commits one's safety to them; but if these particular people had done so, we should perhaps not have had such a good story. The result of the mistake was that they never reached the Moon at all, but circled round it; and by an ingenious device they ultimately came back to Earth. I hope you will read all their adventures for yourselves.

In recent times, Mr. H. G. Wells has written about a supposed visit to the Moon, called *The First Men in the Moon.* He had not quite the courage to explode his travellers out of a huge cannon like Jules Verne, and so he invents a curious material called Cavorite, which screens off gravity (we shall have a good deal to say about gravity in a moment).

Mr. Wells relates how a car, covered with this strange material, can rise quite smoothly from the Earth without the fearful explosion : and the occupants of the car are thus able to reach the Moon, where they find that the inhabitants are like insects rather than like us men and women : and though they are smaller and weaker than we are, their cattle—their " moon-calves "—are immensely greater than ours. There are plenty of exciting adventures in this book too, and Mr. Wells has tried to keep as nearly as he can to what is possible, according to such information as our telescopes give us about the Moon. Of course, his " Cavorite " material is as yet quite unknown—we have not even an inkling of an idea how to screen off gravity; but if we agree to make him a present of this rather startling notion, he uses it very skilfully to pilot his readers through varied experiences. Such books as those of Verne and Wells are worth reading, not only by a " juvenile audience " such as this, but by astronomers too : it is a most useful lesson to them to try and specify exactly where the author is keeping within the possibilities, and where he is making a real mistake. Let me mention one more of such books which I have read with keen pleasure—*A Honeymoon in Space*, by Mr. George Griffith. I think you can buy it for sixpence, and it teaches us a lot of astronomy in very pleasant fashion, because we have not the idea of lessons in our minds when reading it; and it is much nicer to avoid lessons if we can. I am afraid I shall not be able to avoid the appearance of giving lessons so skilfully as Mr. Griffith or Mr. Wells, because for one thing I am not going to attempt to tell

a connected story as they have done. What I shall endeavour to do is to bring before you some of the difficulties of making such voyages, so that you may understand as clearly as possible how they arise: which of them we may hope to get rid of in time, and which seem beyond our powers. And we shall begin to-day with the first difficulty of getting away from this Earth at all.

Why is it so difficult to get away? If we jump up we come down again. We call the reason "gravity," and sometimes we are tempted to let the matter rest when we have given a name to the difficulty. But I want us to think a little more about it than this: to think about what the nature of it is, and also about the great men who found out for us what gravity is. Because it took a great deal of finding. About 2000 years ago, in Greek times, they had some curious ideas about it. The great Greek philosopher Aristotle said that if you took a light thing and a heavy thing and dropped them together, the heavy thing fell much faster. Here are his actual words; some of you (very few, I hope) may not be able to read Greek, and so we will translate them; but it is better to show you the actual words that Aristotle used, because what he said seems so strange to us now.

ὁρῶμεν τὰ μείζω ῥοπὴν ἔχοντα ἢ βάρους ἢ κουφότητος, ἐὰν τἆλλα ὁμοίως ἔχῃ τοῖς σχήμασι, θᾶττον φερόμενα τὸ ἴσον χωρίον, καὶ κατὰ λόγον ὃν ἔχουσι τὰ μεγέθη πρὸς ἄλληλα.

"We see that bodies which have a greater tendency of heaviness or lightness, if they are otherwise

similar in shape, pass more quickly through the same space, and in the ratio which the magnitudes have to each other."

What it comes to is this, that if you have a ten-pound weight and a one-pound weight and you drop them together, the ten-pound weight will fall ten times as quickly. The *magnitude* of the weight settles how quickly it shall fall. That seems to us so astonishing that we can hardly imagine that any one believed it. Yet people went on believing that for 2000 years—just because Aristotle had said it.

Now is it better to believe things people tell you, or is it better to try and find out for yourselves? That is about the hardest question to answer that can be set. At first sight it seems better to believe what people tell you. They may tell you, for instance, that fire burns; and so you need not put your hand in the flame to find out. Or they may tell you that something is poisonous; and if you believe what you are told, you avoid eating it and continue to live. If on the other hand you persist in trying for yourself, you may die; and there is the end of trying things. In this way we seem to have answered our question pretty easily : it seems far better to believe what you are told, because you get all the advantages of other people's experience : and perhaps if they would confine themselves to telling us what they had actually tried, we might be satisfied with this answer.

Unfortunately, however, we cannot always be sure that people are speaking from experience : sometimes we are quite sure that they are not; for instance, we are sure that Aristotle had not tried

the experiment of dropping two different weights; if he had, he would have written something very different. Yet he was believed because he wrote so confidently, and because people had a great respect for him in other ways, and perhaps most of all because we are taught in childhood to believe what we are told. The boy who likes to try things for himself is regarded as a troublesome and naughty boy, and is apt to get a whipping, even if he does not get burnt or poisoned. Yet the world has good reason to be very thankful to some of these naughty boys who have persisted in trying things for themselves.

Galileo was one such, and came in for punishment at the time: here on the screen you see a copy of a fine picture in the gallery at Cologne showing his punishment in prison. His troubles began when he first questioned this statement of Aristotle that a ten-pound weight would fall ten times as quickly as a one-pound weight, and by his trying the experiment for himself he first threw some light on this problem of gravity—the force which prevents our getting away from the Earth. Galileo was born at Pisa, a little town in the north of Italy, famous for its leaning tower. He went to school at Florence, not far away; and was determined to become a professor of mathematics. Several times he seemed to have a good chance of such a position, and was disappointed; but ultimately, to his great delight, he was elected Professor at his native city of Pisa, and he made use of the leaning tower to try his famous experiment with a ten-pound weight and a one-pound weight. In the presence of many witnesses, who

had all pinned their faith on Aristotle, he dropped the two weights together; and they struck the ground together, showing that Aristotle's statement was quite wrong. Even then—such is the reluctance to abandon an old idea—people would not believe

Galileo dropping the two weights from the Leaning Tower of Pisa.

the thing they saw with their eyes. Such was their profound respect for Aristotle that they declared that there must be some mistake in the experiment, since Aristotle could not be wrong.

In honour of Galileo's memory, I want us to try this experiment to-day, as well as we can. We have

no leaning tower, but the roof of this building is pretty high : we have no Galileo, but some one has kindly offered to represent him, and he will drop these two balls, a wooden one and a leaden one, from the roof overhead into this box of sand, so that we may see for ourselves whether they fall together or not. There ! you see they fall together just as they did 300 years ago from Pisa's leaning tower. Perhaps you may think that Galileo's representative did not drop them quite fairly together? That is quite possible, though I feel sure he tried to do so; but to make quite sure of being fair we have arranged a kind of trap for the balls up aloft which can be worked from below by means of this long string, which perhaps one of the audience will pull for me.

There again ! they have fallen, you see, quite together; and do you see that the wooden one is lying on the top of the sand while the leaden one has quite disappeared? It is buried so deep in the sand that it is quite difficult to find it. This fact does not concern us very much at the moment, though it is interesting as showing the different weights of the two balls; but when we come to speak of meteorites in the next lecture, we shall find it useful to remember how a body striking the Earth may bury itself deeply. A very great man, Charles Darwin, used to say that we ought to learn all we can from an experiment, whether it is of immediate importance or not : and this tendency of heavy falling bodies to bury themselves in the earth is just such an extra consequence as he would have delighted to note.

But to return to the main point; there *may* have been, perhaps, a *little* difference between the times of the two balls: indeed there certainly was, and we know the cause of it. It is the resistance of the air, which acts more effectively on light bodies than on heavy. For two solid balls such as we have used the difference is not great: but if we took a feather or other very light body we know that it would fall very slowly. This does not mean that gravity acts less on a feather than on a piece of lead, but that the air resists its fall more effectively. If there were no air, the feather would fall just as quickly as the balls of wood and lead. I cannot show you this by exhausting all the air from this room, because we want some of it to breathe, but if you will kindly be content with a much smaller drop, we can do the experiment with this tall jar. It is an experiment which has been done many times before and is called the "coin and feather" experiment. The coin used to be a golden guinea, but I fear none of my audience is likely to have such a coin with them, and perhaps they might not even like to lend me a sovereign, so I must use one of my own. We put a feather alongside it in a little trap, rather like that which released the balls, and then we close the tall jar over them and exhaust all the air. In old days this was done with a hand-pump, and required some exertion, but with the beautiful resources of this Institution we have merely to attach a tube and turn a tap; in a few seconds we have a nearly perfect vacuum. And now, if we release the trap, you see that the coin and feather fall together. Directly we turn the tap again and let the air in, the feather blows about while the

coin rests stolidly at the bottom. Here, again, is a thing worth noting that is not immediately before us—this rapid inrush of the air from outside into the exhausted space. If the jar had been full of air and the outside empty the rush would of course have been the other way and would soon have left very little in the jar. Now in Jules Verne's book, of which I spoke early in the lecture, the brave men who went in the projectile took with them a dog, and the poor dog died. They thereupon opened a trap-door and put it outside; but I fancy this would have been much more difficult and dangerous than Jules Verne thought, because though the travellers had taken the precaution to carry plenty of air with them inside their projectile, there would be very little outside it when once they had got some distance from the Earth. We shall see in the next lecture how very shallow our atmosphere is—the projectile would pass right through it in a few seconds. Hence, when the trap-door was opened to put out the body of the poor dog, I fear all the air would have rushed out almost at once, and the men would have died too, and so would the story.

If we want the story to go on, we must let Jules Verne tell it in his own way: but there is no harm in making mental reservations, and we will take the opportunity to make one more, because it brings to our notice another fact about Gravity, in which we are specially interested to-day.

We have already said that when we jump up we come down again because of Gravity—because the Earth pulls us to itself. Now when Jules Verne's travellers opened the trap-door and put the poor dog

out—probably with a fairly good push, because they would be in a hurry not to let more air escape than they could help—when they pushed the dog away from the projectile, would it fall back again on to the projectile as we fall back on to the Earth when we push ourselves away by jumping? We know that the Earth pulls things to itself, but do other bodies also pull other things to themselves in the same way? We can scarcely believe that they do because we never feel the pull of anything but the Earth. If I stand near an object such as this desk in front of me I do not feel any pull towards it, and yet, as a matter of fact, it is pulling me and so is everything else in the room, though the pulls are too slight for me to feel. That is one of the laws of Gravity, that everything is pulling or attracting everything else; but the amount of pull or attraction depends firstly on the size of the body that pulls, and secondly on its distance away. The great Sir Isaac Newton first proved these laws some 250 years ago, and we will presently recall how he did it, just as we have recalled Galileo's experiment to memory. But for the moment I only want you to notice one point—that a large body like our Earth exerts a greater pull than a small one like this desk or like the projectile from which Jules Verne's travellers pushed the dog. Undoubtedly the projectile would try to pull the dog backwards, but owing to its small size it might not succeed, and then the dog would go farther and farther away. We cannot tell what would happen without knowing how hard the dog was pushed out. If a thing is pushed hard enough it can get away even from the Earth—indeed, that is exactly the point of

Jules Verne's story, how a very hard push, from a huge cannon, sent the projectile right away from the Earth. The push had to be very hard indeed because the Earth is so big that it pulls very strongly : the pull of the little projectile would be very feeble indeed so that even a very slight push would send the dog right away, never to fall back. This, however, is not what happens in the story : the dog neither goes right away nor falls back, but goes round and round the projectile as a " satellite," that is, as our Moon goes round us : and here I am sorry to say Jules Verne makes another mistake, though it would take too long to explain why. Let us be satisfied for the moment to notice this great fact that a large body pulls harder than a small one. Perhaps you think that is not surprising, perhaps it seems natural to expect more from a large body. Let me remind you that it was just by following what seemed natural that Aristotle made his big mistake : it seemed to him natural to expect a large body to *fall* quicker than a small one, and he was wrong, as Galileo proved by trying it. If I had no better reason than that it seemed natural, I should not ask you to believe that a large body pulls harder than a small one; but there is a much better reason, namely that the experiment has been tried many times.

One famous experiment was made in 1798 by Henry Cavendish (of the same family as the Dukes of Devonshire), but it is by no means the only one : the experiment is really being made by astronomers every day, for if the fact were not true none of their calculations would come right as we know they do.

Well, then! we may accept this fact that all bodies, even the tiniest little particles, are pulling as hard as they can, though particles cannot do much. It is only when a great crowd of them are massed together to make the Earth that the pull becomes easy to feel. And when we get an enormously greater crowd still, such as the Sun, the pull is enormously greater. Why, then, does not the Sun pull us away from the Earth? Well, there is more than one reason; but one at least is that he is so much farther away, and this brings us to the next fact we have to notice about Gravity—that it depends on the distance.

A body close to you pulls hard: take it farther away and the pull becomes less. Mathematicians say that it diminishes as the "inverse square of the distance"; but we can put the law into simpler language in this way. Take a body twice as far away, and the pull is one quarter of what it was; bring it twice as near, and the pull is four times what it was. And now let us go back to the history of the discovery and see how Newton found this out for us.

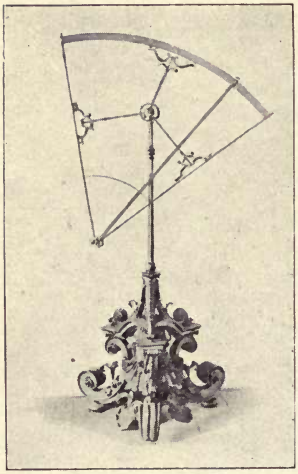
About the time when Galileo lived in Italy, there was another wonderful man called Tycho Brahe, living in Denmark, who also mistrusted some of the things told him on good authority. For instance, there were books giving the positions in which the planets *ought* to be seen at any time, which were still trusted although the planets could be seen not to follow the books. Tycho determined to go to work for himself, observing carefully the movements of the planets with the idea of making better books or tables than those in use. A beautiful observatory

was built for him on the little island of Hveen, and he called it Uraniborg—Heavenly City—because it was devoted to the study of the heavens. Kings and nobles visited him there out of respect for the

Tycho Brahe's Observatory on the Island of Hveen.

great work he was doing : and he himself had such reverence for it that whenever he observed the stars and planets he put on his richest robes. The telescope had not yet been invented, so that his observations were made by the use of " sights " such as are used on rifles—a " back "-sight near the eye, and a

"fore"-sight at the further end of a straight bar pointed towards the star. Compared with what we can now do with a telescope the observations were rough indeed; and yet they were the means by which we learnt the laws of Gravity. This, however, was not until many years after Tycho Brahe himself was dead: he made thousands of observations, but did not live to find out all they could tell him. Fortunately he had a devoted pupil, Kepler, a German, who went on working at them, and found out the very important things they showed. Kepler is represented with a pair of compasses in his hand, showing that he was fond of *measuring* things, which is really the chief business of an astronomer — not merely looking at the stars and planets, but *measuring* their distances apart, or something else that can be measured. Tycho Brahe was also animated by this devotion to measurement, otherwise Kepler would not have been able to use his work as he did. By use of it he found three great laws of movement for the planets. No one suspected the simple laws of Gravity as yet, but Kepler made it possible to find them by establishing the three great laws of movement which have ever since been called by his name



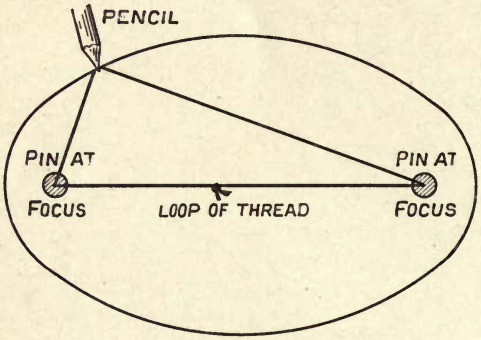
A Sextant used by Tycho Brahe.

— Kepler's Laws. The first is that the planets move round the Sun in ellipses. You can easily draw an ellipse for yourself with two drawing-pins and a loop of string. Fix the pins in a drawing-

Nil dat. quod nihil est?!
J: Kepler

board and put the loop of string round them, keeping it stretched into a triangle with a pencil point. You can still move the pencil about and it will draw you an ellipse. The drawing-pins are called the foci of the ellipse, and when a planet moves in an ellipse the Sun is at one of the foci. Once when the late

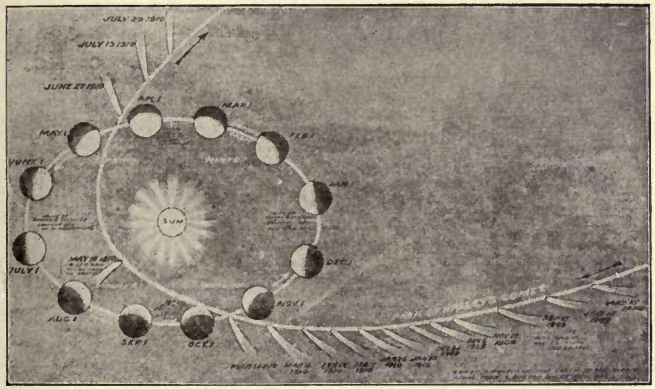
Sir Robert Ball (who several times gave these Christmas lectures) had mentioned this fact that the Sun occupies *one* of the foci of the ellipse, he was earnestly implored by a lady after the lecture to tell her *which* of the foci was the one. I am afraid I should have tried to explain that it did not really matter, and the explanation might have taken a long time. But Sir Robert was cleverer than that: raising his right hand, he said, " Madam ! the right



DRAWING AN ELLIPSE (FIG I.)

one " (which of course was right in any case), and the lady thanked him warmly and went away quite satisfied. But whichever focus we choose it will be nearer one end of the ellipse than the other. Now Kepler's second law tells us that the planet moves quicker when it is near the Sun than when far away. He put it into more precise form, but that will be enough for us to remember—that when a planet or comet is near the Sun, it bustles along at a great pace, when it is far away it moves more soberly,

and when very far away it loiters terribly. That is really because the gravity or attraction of the Sun is feeble at a distance and strong when close; but Kepler did not quite realize about this attraction, he contented himself with noting that the planet moved more slowly or more quickly. And finally he found a third law, which is rather tiresomely



How the Earth and Halley's Comet move round the Sun.
(See Notes to Illustrations.)

mathematical at first sight, but was the most important of all for taking the next step, and therefore we should pay it some attention.

It states that if a planet be placed at a distance from the Sun 4 times as great as that of our Earth, it will take 8 times as long as we do to go round the Sun completely, that is to say, 8 years; and if it is 9 times as far away, then 27 years; if 100 times as far away, then 1000 years. Can you see how these

numbers are related? Please look carefully at

Simple Number	Square for the Distance	Cube for the Time
1	1 × 1 = 1	1 × 1 × 1 = 1
2	2 × 2 = 4	2 × 2 × 2 = 8
3	3 × 3 = 9	3 × 3 × 3 = 27
4	4 × 4 = 16	4 × 4 × 4 = 64
10	10 × 10 = 100	10 × 10 × 10 = 1000

this little table. Four is called the square of two, because if one square is twice as long *and* twice as broad as another, it is four times the first in size. We are almost reminded of the Red Queen's argument with Alice, "Five times as warm *and* five times as cold—just as I'm five times as rich as you are *and* five times as clever." Poor Alice gave it up like a riddle with no answer: but we must not give it up here, we must go even a step further. When one thing is twice as long *and* twice as broad *and* twice as high, we go beyond the square to the cube.

If we multiply 2 × 2 × 2, we get 8, which is the cube of 2: and when the distance is the square of a number, the time is the cube of the same number.

None of the planets fits these numbers exactly: there is no planet at 9 times the Earth's distance, but Saturn is at 10 times—just a little bigger than 9—and we can therefore see from the table that it will take rather more than 27 years to go round the Sun ($29\frac{1}{2}$ years as a matter of fact). But we need not trouble about the exact figures if we understand the *principle* of this great Third Law of Kepler.

On that law Sir Isaac Newton and others went to work, and soon saw that it told them the Law of

Gravity. You have heard the story of Newton and the apple, which must surely be true, because here is a bit of the actual apple tree from Newton's garden at home: it now belongs to the Royal Astronomical Society and they have kindly lent it to us for this occasion. In the entrance hall you will find a beautiful picture of Newton under the apple tree, thinking about Gravity. But though the story of the apple may be quite true, it may suggest to you what is not true, namely, that he thought out the law of Gravity very quickly after seeing the apple fall. This was not the case: it took him 20 years to work out the great law fully in all its bearings. When he saw the apple fall, he *began* to think; he wondered if the pull of the Earth which made the apple fall, and which brings us down again when we jump up, would still be the same if we could go farther away, or how it would alter; and his thoughts took him farther and farther away till he thought of the Moon, and whether it was feeling the pull of the Earth. And then he must have thought of the movement of the Moon and of other bodies in the heavens, and naturally he would think of Kepler's three laws: and then the third of them, which we have just been talking about, led him to see that if the movements of the planets were in any way controlled by a pull from the Sun, the pull must be weaker at a distance, and stronger close to the Sun: and he calculated how much stronger it would be. Instead of stating the law in the language he used, let us illustrate it with this piece of apparatus, because it is easier to understand a thing when we have something to look at. You can easily make the apparatus for your-

selves. Take two equal wooden bars SA and SB (Fig. 2) and put a screw through them at S, into the side of a ladder. The holes in the bars should be larger than the screw shaft so that they will turn freely. At A and B tie the ends of two *exactly equal* cords ACB and AKB. To the middle (K) of one of them hang the weight W, and hold up the other yourself at its middle point C. You may put something at C to represent a comet—say a bundle of horsehair; and something at S to represent the Sun—say a card circle. For the Sun at S will attract the comet with a force like that of gravity—"the inverse square of the distance" SC. [For those who like a mathematical proof, I put one at the end of the chapter, but the great thing is to try the experiment for yourselves.]

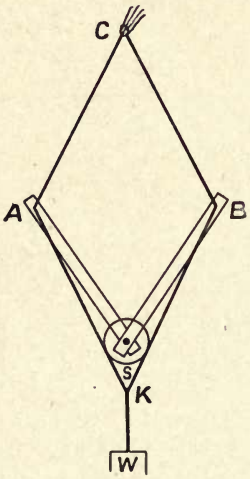


Fig. 2.

Now when you go up the ladder and hold C high up, as in Fig. 2, you will find that it is quite easy to support the weight W perhaps with one finger. You may have to ask some one to lift up the weight for you in the first instance, but once lifted, it is very easy to hold it up. If a pair of reins were made on this principle, a child could hold back a runaway horse.

But now drop C down to halfway so that the bars open out. You will find that the pull is much

greater—four times as great, as Newton tells us. It is not very strong even yet, but it is beginning to be felt. Here is a spring-balance with which we can measure the pull at C, and you will see that the spring is scarcely moved. If again I let C (the comet) come twice as near to the Sun the pull is four times as great again, or sixteen times as great as at first. But now that we are getting nearer to the Sun, which we represent by a cardboard circle, one very important matter forces itself on our attention. Where are we measuring our distances from? Is it from the top of the card, which is the nearest point of the Sun? or is it to be from the centre where the screw is? In a sense we are twice as near the card when we are twice as near the nearest point of it; and there is a good deal to be said for measuring in this way, since the very point we are illustrating is that gravity is so immensely greater when we are close to the attracting body than when we are far away; and therefore we might expect that the part of the Sun nearest would be the important part. At any rate this seems to have been what first occurred to Newton, and he could not get the idea out of his head for twenty years: and the complete

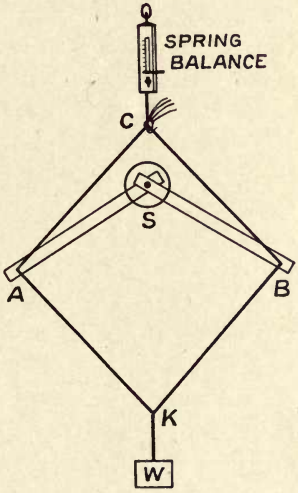


Fig. 3.

establishment of the Law of Gravity had to wait all that time in consequence, just as I have been keeping you waiting to see the end of the experiment. It was only after twenty years' thinking, off and on, that Newton discovered that we must measure all our distances from the *centre* of the Sun, where the screw is. And now, measuring in this way, we will go again twice as near, and the pull is getting very strong (Fig. 3): twice as near again and it is almost too much for me to hold: nearer still and it *is* too much—the weight wins the battle, as you see.

Perhaps you will let me tell you the history of Newton and the Law of Gravity. We shall see from it how much human nature enters into such discoveries at times; and it will have the further advantage of introducing us to another experiment which I want to show you, proving the rotation of the Earth. Newton was born in the year 1642, the same in which Galileo died. (Perhaps we may like to remember that Galileo was born in Shakespeare's birth-year and died in Newton's.) He began thinking about Gravity when the apple fell in the autumn of 1665, when only twenty-three years old; but having got so far as the idea of a pull which altered with the distance, as our apparatus illustrated, Newton was beset by the difficulty we have noticed. It is all very well, he reflected, to talk of the pull altering with the distance, but how are we to measure distance from a large body like the Earth or the Sun? Are we to measure it from the nearest point of the Earth, or from its centre, or from some point in between? When the whole Earth is far away, it does not much matter: but when we are dropping

a weight as Galileo did, from the top of a tower, as at T in Fig. 4, then part of the Earth near F, the foot of the tower, is pretty close to us, and we have just seen how enormous the pull is when we come close to the attracting body. The other side of the Earth at K is 8000 miles away, and the pull will be much less. Suppose, for instance, the tower were a mile high, which is far higher than any tower we are likely to ascend. Even then, the point K is 8000 times as far away as F, and its pull would be 8000 × 8000, or 64 million times weaker. So that when he wanted to add up the pulls from all parts of the Earth together, Newton naturally thought that the far side of the Earth near K would count for very little, and the part near F would be all-important. Even Newton, therefore, did not at first suspect the truth which he found out twenty years later, and which is, that we must measure from the centre C, which is just as near to K as to F. He thought that the correct starting-point would be at some point like R, nearer to F than to K; and he could not make any such point fit in with what was known about gravity at the time when he saw the apple fall, which was in the autumn of 1665. Hence, after puzzling over it for some time, he put the matter aside. Fourteen years later, Mr. Hooke, Secre-

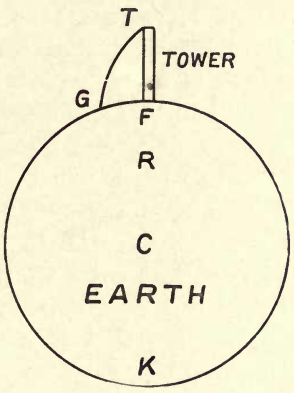


Fig. 4.

tary of the Royal Society, wrote to Newton asking him whether he had any interesting suggestion for one of the meetings. Newton replied in a famous letter, which became even more famous because it disappeared, and was only quoted from memory. Fortunately it was recovered by Trinity College (Newton's College at Cambridge) about thirty years ago, and is now in their library. They have kindly allowed me to show you a picture of part of it, in which Newton makes the suggestion Hooke asked for. He suggested a method of proving that the Earth is turning round on its axis. Nowadays we are all so well convinced of this fact that it seems to require no proof, but the case was very different in Galileo's time, when to state the fact got him into serious trouble. Newton came after Galileo, as we have noticed, and in his day the truth was better known, but even then it was not so firmly established but that he thought it worth proving. And so he suggested that a weight should be dropped from a tower T, much as Galileo had dropped weights from the leaning tower of Pisa; but with a different object in view. This time it was to be carefully noted, not *how quickly* the weight fell, but exactly *where* it fell. If the Earth were not turning round then it would fall at F, the foot of the tower : but if the Earth is turning round, then the weight would be flicked forward a little to G, just as a splash of mud is flicked forward by a rotating wheel (Fig. 4).

The rotation of the Earth can indeed be shown in this way, as Newton thought and as we will presently mention. But unfortunately Hooke misunderstood the point. His mind was full of a different problem,

which had gradually come to the front as the most important scientific problem there was at the time, and which no one could solve. It was this. If gravity really changed with the distance as Newton had suspected fourteen years before, and as many others had since suspected from study of Kepler's great Third Law, then would Kepler's Second Law follow as a consequence, that is to say would the planets all move in ellipses round the Sun? People felt that probably this was a necessary consequence, but no one could prove it. Hooke claimed to have proved it, but no one now believes his claim. And he accused Newton of not knowing the fact, much less being able to prove it. This made Newton very angry. He first sat down and proved the proposition for his own satisfaction—did what every one was trying to do and could not—and then he tossed the matter aside, as he could not bring himself to reply to the disagreeable man who had wrongly accused him. And so things might have remained had it not been for Edmund Halley, a man of a very different kind, who came in the nick of time to rescue this great achievement of Newton's. Halley was an Oxford man, Newton was at Cambridge: Oxford and Cambridge often meet in friendly rivalry, but this time they met in co-operation, and took each a share in the great discovery of Gravity, though the share of Cambridge is of course much the greater. Halley had tried without success to get an answer to the difficult question whether planets moved in ellipses because the Sun attracted them in the way suspected; and as a forlorn hope he travelled all the way to Cambridge to ask Newton about it. To his

great delight, Newton replied that he had proved the proposition completely; though oddly enough he could not find the paper on which he had written it out. Newton was not careful and tidy, as we all are, I hope. But he was very, very able: and soon wrote out a new proof and sent it to Halley, who had already hastened to London to tell the Royal Society the good news that the great problem was solved. This was, however, rather premature exultation, though no one suspected it but Newton. He knew that there was still the formidable difficulty we have noticed: he had not yet found out where to measure the distance *from*, whether from the nearest point of the Earth (or other attracting body), or its centre, or some other point. But so much had he been stimulated by Halley's visit and genial influence, that he forthwith attacked this difficulty again, this time with success: he found the astonishing result that you must measure always from the Earth's centre.

We may therefore summarize the history of this great discovery in three steps—

(i) In 1665 Newton saw the apple fall, and was led to think of the Law of Gravity: "the attraction is inversely as the square of the distance." But he could not see how to measure the distance accurately.

(ii) In 1679 he made the suggestion of proving the Earth's rotation; and Hooke's reply irritated him into solving "the problem of the ellipse"; the solution, however, he kept to himself.

(iii) In 1685 Halley's visit elicited the solution and stimulated Newton into finding that the distance must be measured from the *centre* of the attracting object.

You see what an important crisis it was when Newton suggested his experiment for proving that the Earth rotates : and in honour of him we will now make such an experiment, though not the one he suggested. I might perhaps have shown you his very experiment, or one founded upon it : for during the last few years the rotation of the Earth has been proved and measured in this way, using, however, the apparatus known as Atwood's machine, to drop the weight. Here is a fine Atwood's machine, which has often been used in this Institution : you see two weights, one heavier than the other, connected by a string over a pulley. The heavier weight falls, pulling the other up; but the fall is comparatively slow, and can be made as slow as we please by making the weights nearly equal. Now this slow fall gives the sideways " flick " due to the Earth's rotation plenty of time to develop. When the experiment is made just as Newton described it, the fall is so rapid that the " flick " has scarcely time to work : with Atwood's machine, it gets a much better opportunity. And where do you think this ingenious development of Newton's idea has been put into practice and the rotation of the Earth demonstrated and measured? Why ! at the observatory of the Vatican, where 300 years ago things were made so unpleasant for Galileo merely because he asserted this rotation. Truly Time brings changes !

But this beautiful method of Father Hagen is perhaps not the easiest way for us to see the rotation of the Earth within a few minutes. We had better use the method of an ingenious Frenchman called Foucault, who used for the purpose a long pendulum like

this. If you swing a pendulum truly backwards and forwards, without any wobble, it will go on swinging in the same way even though the Earth rotates underneath it. Here is a little pendulum mounted on a model earth : I set it swinging and turn the model earth round—the pendulum still goes on swinging in the same way : it takes no notice of the rotating Earth underneath, though I have turned the model a quarter turn (so that if the pendulum went with it, the swing would be at right angles to its former direction). If, however, there were people living on this model earth, they would not be conscious that I had turned it round : to them the pendulum would seem to change : to them it would *seem* to be swinging now at right angles to its former direction. And so our long pendulum will not really change, but will seem to us to be changing. But to turn our actual Earth a quarter round takes six hours : we should have to go home to tea long before that : we must be satisfied to watch the real pendulum for a few minutes only. Nevertheless we can see its apparent change if we magnify it in the ingenious way devised by Sir James Dewar.

Here is the pendulum tied back. Presently I am going to swing it by burning this string which ties it up. When the string breaks in burning, the pendulum will swing backwards and forwards. At one end of the swing it comes very close to this lamp which is throwing the shadow of the pendulum-wire on the screen, and you will then see the wire and the motion much magnified; so that we can easily tell whether the swing changes even a little bit. But it is not the pendulum that is changing, it is the Earth

rotating underneath; and in a minute or two we shall see the effect of the earth moving.

[In Fig. 5 the pendulum bob was at first swinging from D to C; the shadow being thrown on the screen from the point X was near the middle of the screen most of the time, but as the pendulum bob reached the point C, the shadow fell at *c*, away to the right. Presently the earth's rotation altered the path of the bob to BA, and at A the shadow fell at *a*, away to the left.]

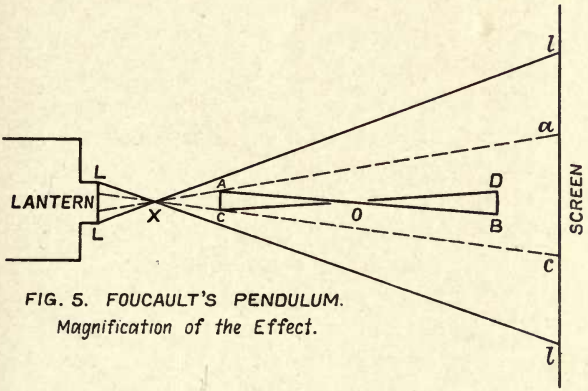


FIG. 5. FOUCAULT'S PENDULUM.
Magnification of the Effect.

You will see that as the pendulum comes up to the lamp the shadow will flash to the right, and it would go on doing that always if the earth did not move; but as the earth moves it will presently go to the left. There will be a moment when it will spread out on both sides; and after that it will go to the left. I hope we can manage the experiment without keeping you too long. Now I will burn the thread. There, you see it goes to the right, and presently it will go to the left. You remember when Peter Pan

asks those who believe in fairies to clap their hands? Well, I don't want you to believe in things you do not see, but when you *see* the Earth rotating, that is, when the shadow goes to the left instead of to the right, then you clap your hands; for then you will have seen the rotation of the Earth. Surely it is beginning to go over now, it is more to the left than to the right! (The audience here testified as requested.) In this way you can soon see the Earth rotating, if the experiment is carefully prepared beforehand.

There is another way in which it has been shown by M. Foucault that the Earth is rotating. He showed it by means of a gyrostat. He spun a top quickly and set it up in a certain position. Now a thing that is spinning has got a great tendency to remain in the same position. For instance, we know that a spinning top does not fall down, though it may turn round. I cannot show you M. Foucault's exact experiment, but I can show you some pretty things of the same kind which tell us as much as we want to know. Perhaps you have played with gyrostats already: but probably you have wound them up with string; Mr. Gray, of Glasgow, has invented some beautiful gyrostats which are wound up by means of a small motor. Here is one now spinning very quickly, and if I put it horizontally with one end of the axis on a stand, it will not fall down, as it would if it were not spinning, but simply goes round and round. Its weight *tries* to make it fall, but can only make it turn round. And if we *try* to lift the end of the axis, we only make it turn round the other way.

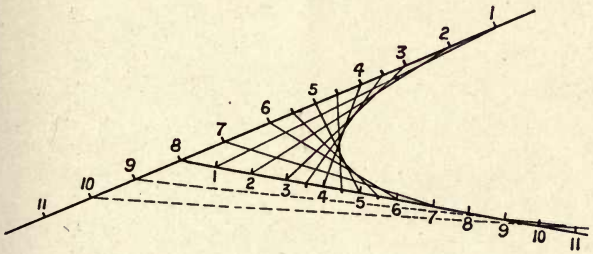
That principle has been used recently for steering ships. A large gyrostat has its axis floated horizontally in mercury. If the axis points East and West, then the rotating Earth is always *trying* to lift the West end, but it only makes the axis turn round. And this is also more or less true for any other position except that when the axis is due North and South. Hence the axis will be always seeking that due North and South position, as the magnetic needle seeks the Magnetic Poles. This has been known a long time, but only recently has the tendency been used to make a good practical compass. This has at last been done, and the most wonderfully convincing proof of the rotation of the Earth is thus provided—we are steering ships by means of it, and entrusting thousands of lives to its efficacy.

Perhaps it will interest you to know what was the nature of the invention which has made a practical success of this compass. You have seen a workman use a plumb-line to get buildings vertical, and you know that a plumb-line is very like a pendulum. If you set it swinging it will go on swinging for some time, and be no use as a plumb-line. To bring it to rest the workman sometimes puts the bob in a bucket of water, which quickly stops the swinging. This kind of stopping is called "damping" the swing, though it has nothing to do with the water wetting the bob; it merely means that the inconvenient swinging is stopped. Now when a gyrocompass is set up, unless it is pointed *exactly* North from the first (which is unlikely), it will swing to and fro to find the North, just as a plumb-bob swings to and fro to find the vertical. But the swinging of the

gyrostat will be much slower and more persistent than that of the pendulum—so slow and so persistent that most people thought it impossible ever to bring it to rest. But some ingenious Germans have actually found a way, and their invention (which corresponds to the bucket of water with the plumb-bob) has made a practical success of the compass. The gyrostat in spinning round at a great rate makes air currents; and the inventors have led these air currents past a delicately adjusted metal tongue, so that any tendency to swing is resisted. Perhaps it will also interest you to hear how they came to pay attention to the matter at all. They had the notion of going to the North Pole by submarine. They thought that a boat could be sunk so as to travel under the ice to the North Pole and back. But the question arose how they were to steer. The magnetic compass would only take them to the Magnetic Pole, which is several hundred miles away from the true North Pole. The stars would not be visible from under the ice. Hence they had to think of some other plan, and it occurred to them to enquire whether they could not make use of this long-known but never-used principle of the gyrostat setting its axis North and South. Their success has been so complete that their compass is actually superior to the magnetic compass.

But we must now return to Newton and the law of Gravity. Newton proved, then, that the law of Gravity made bodies move in ellipses. An ellipse is called a conic section, because if you take a cone and cut it across you may get an ellipse. But it is not the only possible curve; you may get a parabola

—a curve which does not go round and come back again, but goes on for ever. I can show you how to make a parabola, which is just as easy as to make an ellipse, I think almost easier. Take two straight lines, and set off on each a series of equal distances—let us say inches, or half inches, or whatever you like—and then join the corresponding points in the way shown in the diagram, outwards on one line and inwards on the other. I believe in some schools this is done as a needlework exercise, joining the points



DRAWING A PARABOLA (FIG. 6.)

by threads, which shape out a parabola. You need not stop at the point 8; you can go on past it, provided the lines are suitably extended, and there *is* no stopping-place: so you see a parabola is a curve that goes on without end. That is important to remember: for suppose we started on a journey from the Earth and moved under gravity we might get into one of these curves that goes on without end, and that would be inconvenient, for we should never get back again to Earth.

At one time it was thought that comets moved in parabolas and never came back; that they came to

us once, went away and never came back at all. But soon after Newton's discovery about the law of Gravity, Halley thought he would calculate the orbits of these comets. Perhaps you have not seen a big comet, such as that which appeared in 1858.

The Great Comet of 1858.

A " comet " means a hairy star, and in old days comets were represented as stars with hair. Nowadays we get photographs of them. Anybody who has got a Kodak and can strap it to a telescope *with clockwork* can take a photograph of a comet.

Well, it was supposed that comets moved in para-

bolas, as we should if we started off with the proper velocity; and it was thought they never came back. Halley found out that they did come back, and that comets move in ellipses as other planets do, only that they are very long ellipses. It was a well-deserved reward for Halley, who took such pains to get the proof of the law of gravitation from Newton, that he should be led to this great discovery. I may add to what I have already told you, that even when Halley took Newton's great work to the Royal Society in triumph, he found to his astonishment that they were at the moment too poor to publish it. Thereupon Halley paid for it out of his own pocket, although he was not a rich man. He got his reward when he made this great discovery about comets coming back to us, and that was soon after he went back to Oxford as Savilian Professor of Geometry.

He set out to examine as many orbits of comets as he could find observations of—assuming that they went in parabolas and never came back—and he calculated the orbits of twenty-four of them. Now the calculation of an orbit is a complicated matter that I am not going to trouble you with, at present at any rate; but we can all of us understand that when figures come out the same, whatever the figures may mean, they must refer to the same thing. Look now at these figures which Halley obtained for three comets which were thought at that time to be quite different. One of them had appeared in 1531, the second in 1607, and the third in 1682; and when Halley calculated the particulars of their orbits quite separately and independently he found—

Year of Comet	Node	Perihelion	Inclination	Distance
1531	49°	301°	18°	0·57
1607	50°	302°	17°	0·59
1682	51°	302°	18°	0·58

The figures are not *quite* the same, but they are so nearly the same that if we tried to draw the three orbits we should find the pencil going over the same line as nearly as possible : and Halley immediately said that instead of three separate comets, the same one must have come three times, in the same path, which it took about seventy-six years to go round. The path must, therefore, not be a parabola, which does not admit of return, but a long ellipse. And the comet would continue to pay us visits every seventy-six years, the next visit being due in 1758. He knew that he would be dead then, but he hoped that when his words came true, the world would remember to credit an Englishman with the prophecy. Here are his actual Latin words—in those days scientific papers, intended to be read by the whole world, were written in Latin—a language all nations knew, though they might not know the language of their next neighbours.

> Quocirca si secundum predicta nostra redierit iterum circa annum 1758, hoc primum ab *homine Anglo* inventum fuisse non inficiabitur æqua posteritas.

He was proud of his achievement, not for himself but for his nation; and that national pride is appreciated not only by us, but by other countries. My

friend, Mr. Hollis, when in Paris one day, saw a picture of the supposed return of Halley's comet; he bought it, and has allowed me to reproduce it here. An angel is calling Halley from the grave to see the

The Return of Halley to see his Comet
(By a French Artist.)

return of the comet, the fulfilment of the prediction he ventured to make.

When Halley had once shown that the comet comes back every seventy-five years, it was easy to calculate when it had appeared before, and they found that it was the comet mentioned by Josephus

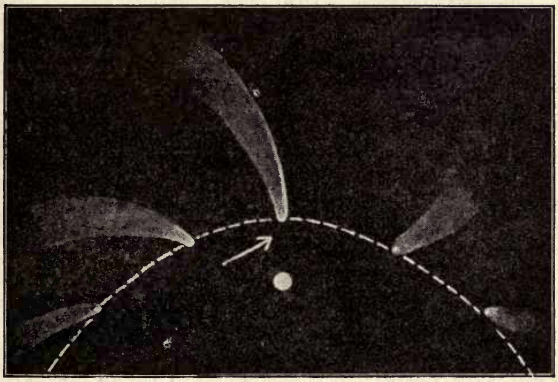
as having appeared at the siege of Jerusalem. Josephus recorded "a fiery sword hanging over Jerusalem," which foretold its destruction. People were terrified of comets in those days, and generally associated them with disaster: and it was only when Newton and Halley showed that comets obey regular laws that this fear was dissipated. It is seldom very difficult to find some disaster which could be

Halley's Comet on the Bayeux Tapestry.

associated with a comet, and we shall find that on several occasions Halley's comet has been associated with some event in our own national history. For instance, it appeared in 1066, at the time of the Norman Conquest, and it is represented on the tapestry that Queen Matilda made—the Bayeux tapestry—to celebrate her husband's victory. The English were frightened, and the Normans inspirited, by this wonderful sign in the heavens, and these two different effects may perhaps have decided the battle.

There is one other thing about comets that is in-

teresting because it shows there is another force besides gravity which affects them. The head of the comet feels only the pull of the Sun, which is very strong when it is near the Sun and very slight when far away; but the tail of the comet feels another force altogether, and behaves in a totally different way. Instead of following the comet all the way like the smoke of an engine, it points directly away

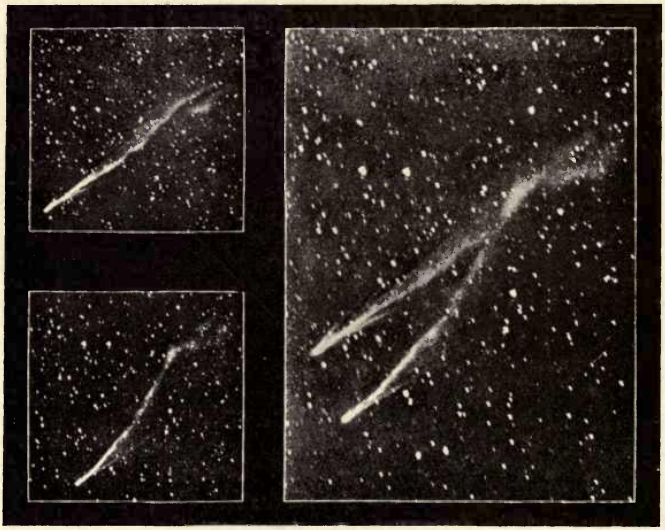


Various Positions of a Comet's Tail.

from the Sun. That is due to the fact that besides gravity that pulls the head towards the Sun, there is another force away from the Sun; it is as though the Sun was blowing the tail of the comet away from the head. Of course there is no actual blowing as one blows with one's breath; it may be electrical repulsion; or it may be light pressure—the fierce light of the Sun acting as a blast would act and blowing the tail out.

We can see this action of the Sun in blowing away

the tail by comparing two photographs taken one after the other. Here is a pair taken by that skilful photographer, Professor Barnard, of the Yerkes Observatory in America. He was the first man to show these beautiful effects. Early in the night he



Changes in a Comet's Tail
(By E. E. Barnard.)

got one picture of the tail; then, by waiting an hour or two, he got another, showing how the tail had changed in the interval. Finally he has very skilfully combined the two pictures, so that the stars on one fall exactly on the stars in the other. You see how the head of the comet has moved, and that the tail is certainly not following it like smoke following an engine. To trace the changes in the

tail requires scrutiny, but with care we see that each feature is being driven away from the head.

We thus realize that though gravity is the principal force with which we have to deal when we are travelling out into space, there are, nevertheless, other forces such as that which acts on the lighter particles of a comet's tail. I hope none of us on the journey will be blown away like the lighter particles.

The facts that the Earth rotates and that it pulls us towards itself by gravity are so familiar to us that we scarcely realize their immense importance, and it may seem strange to you to have spent so much time talking about them. But you remember the old proverb that a cow never knows the value of her tail till she has lost it. If we leave the Earth to take our voyage in space we shall lose both these things. We shall lose the Earth's rotation, and with it the changes from day to night. If the Earth stood fast as our forefathers believed, the Sun and the stars revolving round it, we should retain something of the daily change in our journey : but now we know that it is the heavens which remain still, while the Earth rotates, we must make up our minds to lose the peaceful night with its invitation to sleep. If we sleep at all, we must sleep by broad daylight, for the Sun will shine continuously when once we lose the Earth's shelter. Our watches will tell us the time, but clocks, which are driven by weights, and regulated by pendulums, will be useless when we lose the gravity that pulls the weights down and causes the pendulum to swing. It was Galileo who first found out that a pendulum kept time, and he made the discovery in the cathedral at Pisa when the lamps

were lit. There was a lamp hung like a long pendulum from the roof: and the verger pulled it toward him to light it and then let it swing back. Galileo thought that as the swinging died down it would become either slower or quicker, and to test this he timed the swings with his pulse: to his amazement they were all made in the same time. He naturally tried other pendulums for himself, and found that they all had this property of keeping time—though the swing may alter in size it does not alter in time. One way of realizing this property of the pendulum

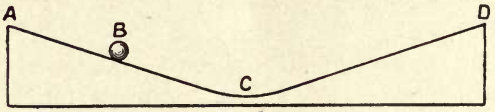


Fig. 7.

is to take something else which swings to and fro, rather like a pendulum, and yet does *not* keep time, such as this pair of inclined planes AC and CD (Fig. 7), in which a groove is cut so that a ball B can run down AC and up the other side CD, the join at C being rounded so as to avoid having a bump which would stop the roll. The ball swings back and forward rather like a pendulum, as you see, but it does not keep time. The short swings at the end are made much more quickly than the long ones at the beginning. But when we swing a pendulum and let its swings die down there is no such quickening, and hence the usefulness of a pendulum in regulating clocks, and the usefulness of a clock is to tell people like lecturers to stop talking after a reasonable time, before you are thoroughly sick of them and their gravity and levity both.

Note on the Gravity Experiment

The arrangement described on p. 22 is called a "Peaucellier Cell," and can be used to draw a straight line. It was Sir G. H. Darwin who first pointed out that it could be used to illustrate gravity.

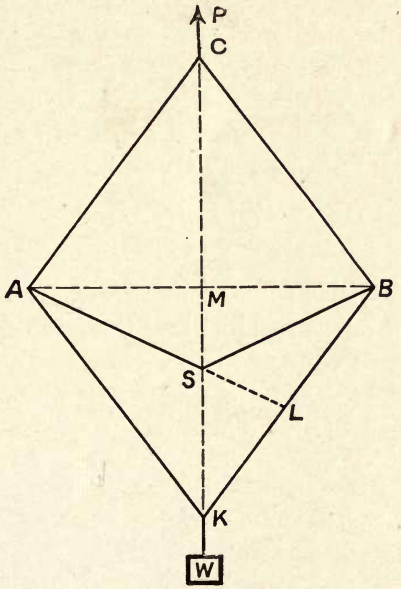


Fig. 8.

Notice that (Fig. 8)

$$\begin{aligned} CS = CM + MS &= KM + MS \\ SK &= KM - MS \\ \therefore\ CS \,.\, SK &= KM^2 - MS^2 \\ &= KA^2 - AS^2 \end{aligned}$$

Since KA and AS are a string and a rod of constant

length, the product CS . SK is therefore constant, and it is this property which is used in drawing the straight line; for if K be made to move on a certain circle, C will move on a straight line.

As regards the use for gravity : the pull at P is to the weight W in the same ratio as the tensions in AC and AK.

Now AC is parallel to KB; and thus ALK is the triangle of forces for the point A. The ratio of the tensions is therefore that of KL to KA : or SL to SA, since KS bisects the vertical angle of the triangle : or finally SK to SC, since AC and KL are parallels.

Thus $P/W = SK \cdot SC/SC^2$
$= (KA^2 - AS^2)/SC^2.$

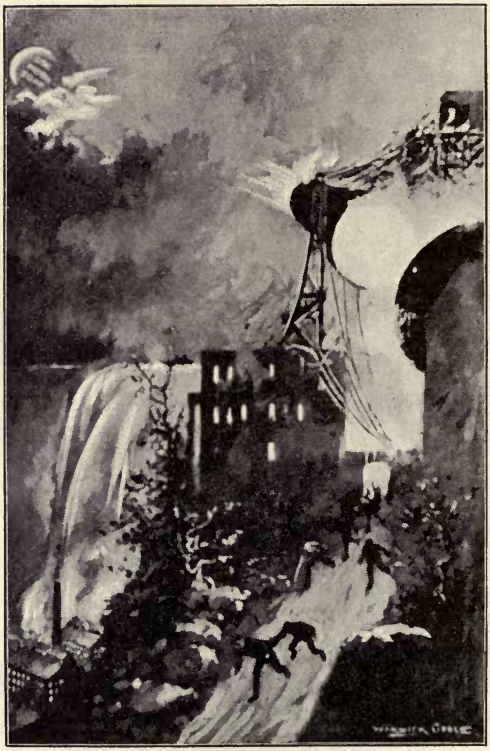
In practice it is convenient to use, instead of the lower string AKB, one just half the length, attached to the middle points of the bars SA, SB : or reduced in any other ratio. The advantage gained is that S need not be so high above the ground.

LECTURE II

THE LENGTH OF OUR VOYAGE AND THE START THROUGH THE AIR

We have talked of the primary great difficulty of getting away from the Earth at all. But it is not quite fatal, for balloons and aeroplanes do allow us to leave the solid Earth in some measure. We have just read in the newspapers that an aeroplane has ascended to a height of nearly four miles, and the question arises whether this is as far away as we wish to go. If we have any idea of visiting the Moon, then it is not nearly far enough, for the Moon is not four, but 240,000 miles away; an aeroplane must beat the present record by a considerable margin if it is to take us to the Moon. It is not altogether easy to realize what such a distance means, even when we remember that it is about ten times round the Earth. A little time ago there was a story in *Pearson's Magazine* of an American who used a huge searchlight apparatus to throw an advertisement on to the Moon, "USE MOON SOAP." The picture does not suggest any great difficulty in this achievement until we remember that owing to the Moon being 240,000 miles away, each of the letters would be hundreds of miles high; and then we begin to wonder whether even the most powerful searchlight

possible would send light enough to illuminate brightly such an enormous area. It seems probable



The Wreck of the imaginary Searchlight Apparatus for advertising on the Moon

(See Notes to Illustrations.)

that it would not. But you can never tell what they may do next in America.

But now I do not want you to take this statement

about the distance of the Moon on my simple word; I want you to know for yourselves how it is measured. We saw what an advantage it was to Galileo to try things for himself rather than take them on trust; and though we cannot exactly measure the Moon's distance in this room, we can imitate the method with something else. We cannot perhaps make so good an imitation as we did of Galileo's experiment, by dropping balls from the roof, but we will make as good an imitation as we can. When astronomers measure the distance of the Moon or of any other object in the sky, they use precisely the same method as surveyors use on Earth, and indeed the method which every one of us uses nearly every moment of our wakeful lives. With our two eyes we are continually trying to estimate how far away men and things are from us. At this moment, for instance, I am trying to see whether the important people are in the front rows [1] and the unimportant people at the back; and I do it really by *squinting*. I turn inwards my two eyes to converge on some one in the front row, and I can feel how much squint it takes: then I converge them similarly on some one in the back row and I feel that it does not take so much. This process is quite unconscious because we have all done it so many millions of times that we do it without thinking, but our muscles and nerves tell us the result just as well. From what they tell me I conclude that the people are pretty much in their right places.

Not only is this measurement of distance with our

[1] These lectures being "adapted to a juvenile audience," the front rows were "reserved for juveniles."

eyes generally unconscious, but it is also vague: that is to say, we seldom express the distances in feet and inches: we usually judge whether one thing is nearer than another, or farther away, or at the same distance. Thus, when I try to light a cigar, I have to use my eyes to tell me when the match is at the same distance as the end of the cigar: for if I put the match nearer I shall spoil the cigar by lighting it in the middle; and if I put the match farther away than the end I shall not get a light at all. This *equality* of distance is gauged by squinting with the eyes; and if you look at your father's eyes when he is lighting a short cigar, or a short stump of one, you will see him squint horribly. But if he has a very long cigar like this,[1] he will squint far less. For that reason it is not *quite* so easy to light a big cigar. If I could get one as long as this room, even if my arms were long enough to put the match near the end, I might not hit the end without some trouble: for the amount of squint would be so small that I could scarcely feel it, and it would be very nearly the same even if I put the match a foot away from the cigar end.

Now astronomers use the same kind of method, and meet with the same difficulties, when they measure the distance to the Moon. Instead of two eyes, they use two telescopes, one at a place we will call A, the other at a place B; and they measure the distance AB, which is called the "base," and is of great importance (we do not need to measure the distance between our two eyes, which is the "base" for ordinary life, because we are thoroughly familiar

[1] A curiosity called a "Giant," purchased at Winchester.

with it, which does nearly as well). The base may be a few feet long, or some miles, or many millions of miles, according to the distance to be measured: but we must know its length before we can measure the distance required. Then the two telescopes at the ends are pointed at the Moon (or other object at the distance to be measured), and we see how much they "squint." Some people may tell you that the proper word for this is the Greek word "parallax": but we will be content to use the good old English word "squint."

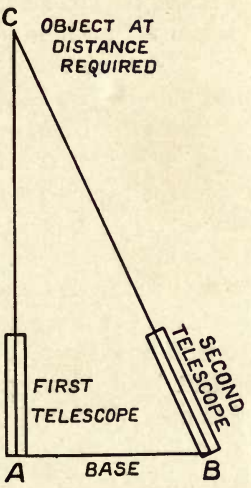


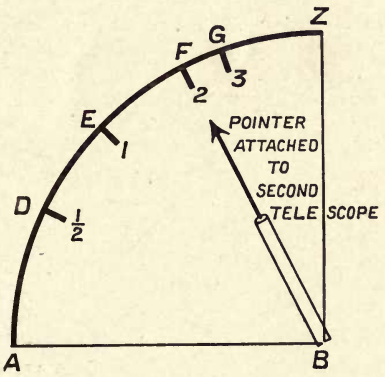
Fig. 9.

Let us try an actual experiment to see how a distance is determined by this squint. To save time we will put all the squint in one eye; that is to say, we will have one telescope (Fig. 9) not squinting at all, but pointing straightforwards from the base AB to the point C. We must measure the length of the base AB with this tape measure, and we will make it just 12 feet, putting the other telescope at B just 12 feet from A. Instead of telescopes, however, through which only one person can look at a time, we will have small searchlights which will make the direction visible to every one. You can all see when the searchlight B is pointed so as to throw its light on to C. To save us time in measuring the different distances I have had various positions of C marked

off at 6 feet, 12 feet, 18 feet, and so on, from A : and you will be able to see on which of these the light falls. But I want one of my young friends to turn his back on the screen so that he cannot see where the light falls : all he can now see is the amount of " squint " marked on this card, and yet you will find that by reading the " squint " he can tell you where the light is falling. Thus I point the telescope and from the " squint " he tells you that the squint is marked 1, meaning that the distance is 12 feet : we change it and he tells you that the " squint " is $1\frac{1}{2}$, that means $1\frac{1}{2}$ times the base, or 18 feet; change it again and he says it is between $\frac{1}{2}$ and 1; or between 6 feet and 12 feet, as we see it is. He can tell just as well what the distance is from the " squint," as we can by seeing it on the screen. And this is no conjuring trick : it is the simplest and most straightforward process : and it is the same process which the astronomer uses to find the distance of the Moon.

But before going on to the Moon, let us consider this card of " squint " a little (Fig. 10). We put 1 for a " squint " on an object just as far away as the base. In our case the base was 12 feet; but the same card would serve if the base were a mile long : when the " squint " was 1, the distance would then be a mile. The mark 2 tells us the " squint " corresponding to twice the base : 3 to 3 times the base, and so on. We can also mark $\frac{1}{2}$ for half the base; or other fractions. But what I want you to note is that all the marks for distances greater than 1 fall in one half of the arc : they all fall between E and Z : in the part AE the marks are all for distances less than 1. Moreover, the distance 2 uses up a considerable part

of EZ, leaving only FZ for all distances greater than 2; 3 uses up still more, leaving only GZ: and yet we have a great many still to come, 4, 5, 6, up to hundreds and millions. All these have to be crowded into an arc which gets continually smaller and smaller, so that we find it more and more difficult to make the marks or to distinguish between them. When you get home, take a card and mark it for yourself and see how many "squints" you can put accurately upon it. You may get up to 10, or 20 even; but you will soon find how difficult it becomes. Probably you have a watch with the 60 minute spaces marked. Well, one minute space is the "squint" mark for 10: divide it into halves and you get the "squint" mark for 20. One half must have all the marks between 10 and 20, the other must have everything above 20! When we use our eyes we have no card, but we attend to the feelings of our nerves and muscles, which can scarcely distinguish between these various "squints" at long distances. That is why it is harder to put the match to the end of a very long cigar than of a short one.



CARD OF "SQUINT"

Fig. 10.

And when the astronomer tries to determine distances of objects in the sky, such as the Moon, he

comes across this same difficulty, since the "squint" is always small, owing to the object being very far away. Now there is one method of getting over this difficulty which I have not yet mentioned: if we could put our eyes at the end of long horns, not like those of a snail, which project *forward*, but horns projecting *sideways* a foot or two, then for both eyes to look at the same object they would have to "squint" much more than at present (Fig. 11). This is because we have made the base much bigger: in-

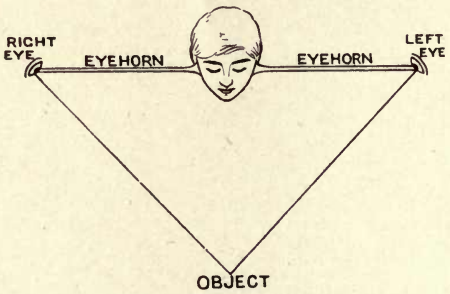


Fig. 11.

stead of being about 2 inches we have made it several feet. We have not heard of any actual men with eyes set on horns in this way: Sir John Maundevile related some wonderful "traveller's tales" in old days, when there was less chance of finding him out than there is now: he wrote

> "of anthropophagi and men whose heads
> Do grow beneath their shoulders,"

but I don't think he ever mentioned any race whose eyes grew on horns. Yet by means of an apparatus

called a " range-finder " which soldiers and sailors use to find the distance of the enemy, they manage to use their eyes just as though they were on long horns.

In Fig. 12 A and B represent the real eyes of

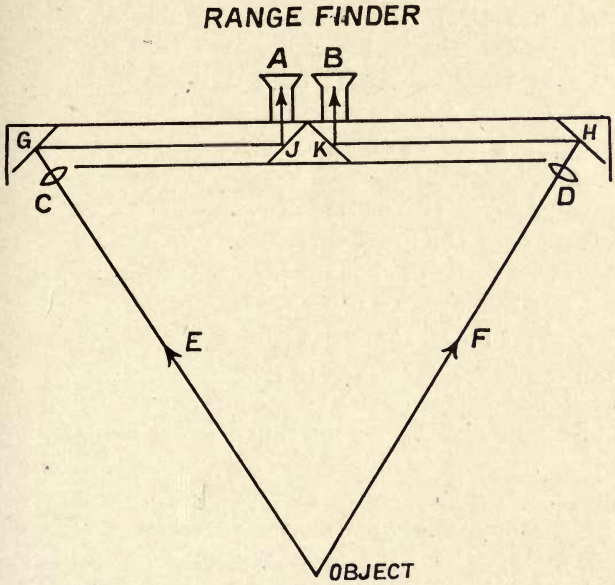


Fig. 12.

the observer, close together; C and D his artificial eyes wide apart. They are two lenses C and D, with mirrors behind them G and H : and these artificial eyes can be turned on the object by screws, just as our eyes can be turned by our muscles. Rays of light EC from the distant object falling on C are reflected by the little mirror behind it so as to travel

along GJ : and another little mirror at J sends them into the eye A. Rays which start along FD are similarly reflected along HKB into the eye B. Hence without moving his own eyes at all, the observer measures the " squint " of the wide artificial eyes C and D by turning the screw (or both screws, if there are two). He then knows the distance of the enemy and tells his comrades for what " range " to sight their rifles. If they did not find out the " range " in this way, the bullets would either go over the heads of the enemy, or hit the ground in front of them.[1]

Now the astronomer is fully alive to this method of getting over the great difficulty. What it comes to is that we make the base as long as possible. Nature has put our eyes so close together that the base is very short : and though it suffices for estimating the distance of a cigar tip, or of people in the same room, it is too short for telling us the distance of the enemy half-a-mile away. So the range-finder is made with a much longer base and the difficulty is largely reduced. But for greater distances still, such as that of the Moon, the range-finder becomes as useless as our eyes : the base is not nearly large enough. Instead of having our artificial eyes a few feet apart, we must put them miles apart ; and we may as well put them as far apart as we can, let us say, on opposite sides of the Earth (Fig. 13) ; and then we find that the " squint " required to set both eyes (that is to

[1] Since these lectures were delivered, the use of the periscope has become familiar to most of us. The eyes on horns could be represented by using a periscope for each eye.

say, two telescopes at the end of the base) on the Moon is quite considerable, and by measuring it we find that the distance of the Moon is 240,000 miles, as I told you. And it was to find out this fact that our Government established the Royal observatories at Greenwich and at the Cape of Good Hope, one in the northern hemisphere and one in the southern. They are not quite as far apart as possible, because one might have been at the North Pole and one at the South Pole: but you will probably agree with

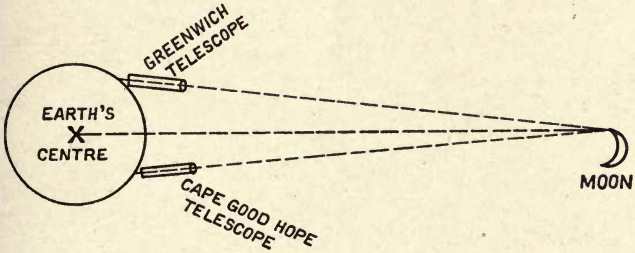
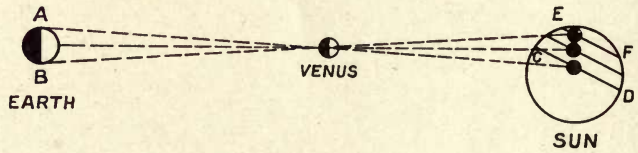


Fig. 13.

me that the astronomers would not have been quite so comfortable in that case, and we have to sacrifice something for comfort.

This old difficulty, however, is not yet done with: it crops up again in a most tiresome way when we want to find the distance of the Sun instead of that of the Moon, because the Sun is still further away—nearly a hundred million miles: and even when our base is the biggest we can get on our Earth, the "squint" required for the Sun is very small, and the difficulty of measuring it very great. The only thing then left for the astronomer is to take advantage of special occasions when the difficulty happens

to be less than usual. Such an occasion was the Transit of Venus. Perhaps my present audience has not heard so much about the Transit of Venus as their parents and grandparents did, because the last Transits occurred in 1874 and 1882, long before you were born: and the next will happen in 2004 and 2012, when all of you will be a good deal older. But the echo of the great sensations may not yet have died down, and so you may have heard of a Transit of Venus and wondered what it was.



TRANSIT OF VENUS FROM OPPOSITE SIDES OF OUR EARTH.
Fig. 14.

What concerns us is that it is simply an occasion when the difficulties of measuring the Sun's distance are less than usual. The base remains the same, because we cannot get away from the Earth: the best we can do is to put our eyes or telescopes on opposite sides of it, and indeed in all parts of it. Astronomers were scattered for the Transits of Venus to such places as the Sandwich Islands, New Zealand, and Australia, Mexico, Kerguelen Island (a very desolate spot), Egypt, and so on: and they watched Venus cross (or "transit") the Sun, and noticed the exact moment when the transit began and ended. You will scarcely want me to explain fully how this told them the Sun's distance; but I think you can see in a general way how they worked it out if you

look at Fig. 14. You can see that for a telescope at A on one side of the Earth, Venus would cross the Sun's disc along the path CD; while a telescope B on the other side would see Venus travel in a different path EF; and you can see also that if the Sun were brought nearer, the two paths would not be so different: if the Sun were further away the paths would be more different. In other words, the amount of difference tells us just how far off the Sun is, *if we can measure the difference accurately.*

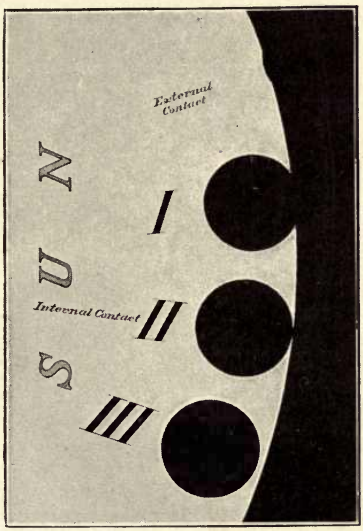


Fig. 15.—An Ideal Transit of Venus.

Unfortunately astronomers found, when the great events had taken place, that they could not measure the difference as accurately as they had hoped. They hoped to determine the exact second when the transit began or ended. It would have been best for them if there could have been a moment such as that labelled II in Fig. 15, when the black disc of Venus just touched the bright edge of the Sun. Before that moment, as in I, it would have been only partly on the Sun, and after it, as in III, the black disc is completely within the Sun. It would have been nice for the astronomers if between I and III

there had been just a single instant like II, which they could note accurately. Then they would have found out the Sun's distance very exactly. Unfortunately it was not so, and they knew from previous Transits that it would not be so. Instead of

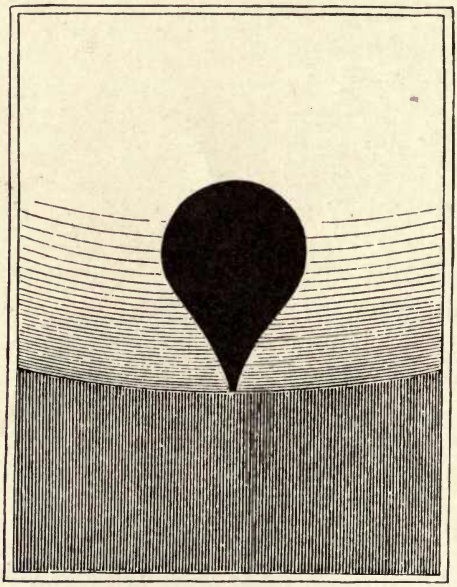


Fig. 16.—The "Black Drop."

an appearance like II, they knew they would see something like Fig. 16, the black disc being not at all round, but pear-shaped. This does not mean that Venus is really of that shape, for when it is fully on the Sun we can see that it is properly round, as in Fig. 17; and we also see that it has an atmosphere like ours, through which the Sun's rays are bent.

The pear-shape is, however, not caused by this atmosphere being illuminated (though this illumination causes trouble of another kind), but by the peculiar behaviour of light when a bright light is screened off. Near the edge of the screen we get peculiar appearances which go by the name of diffraction. You can see them if you look (with one eye only) at the sky through two finger-tips nearly closed together : when they are very close, one seems to go out to meet the other, though you can feel that they are not yet touching. Astronomers knew that there would be these "diffraction" appearances, but they hoped to make good allowance for them by practising beforehand with models of the expected Transit which were ingeniously constructed. But they were disappointed. They knew they had been disappointed long before they collected and compared the observations made at different stations; because two people side by side using similar telescopes gave quite different times instead of the same time. Hence they knew that one of them, and perhaps both, must be wrong: and you cannot get a right result from wrong observations.

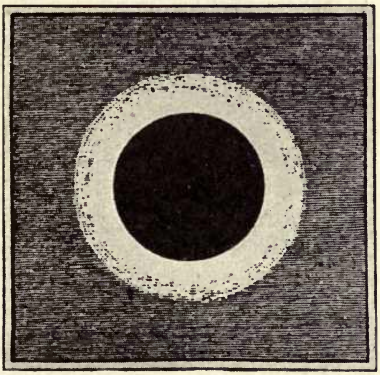


Fig. 17.—Venus and its Atmosphere.

Transits of Venus only rarely occur. We have

said that the next pair (they always occur in pairs like twins) will be in 2004 and 2012, and the last pair were in 1874 and 1882. The pair before that were in 1761 and 1769, and one of the people who observed the Transit of 1769 was the famous Captain Cook, who was killed by the natives of the island of Hawaii ten years afterwards. A more famous Transit still was that of 1639, because it was the first that any one ever observed. It occurred to a young clergyman named Horrox that there might be such a thing, though no one had thought of it before; and he calculated the day on which it would fall, which turned out to be Sunday. He got out his telescope at sunrise, and set it to look at the sun; for he did not quite know at what time the Transit would come. The hours passed on, and it began to get near church time. Then came rather a struggle between duty and inclination. What was he to do? Transits o Venus do not come every Sunday. Was he to go to church and take the service, or to watch Venus? Well, really he had no doubt what he should do. He lived long before Nelson, but he knew what "England expects of every man." So he went to his duty first, and took the service. Should you think that he thought of Venus sometimes? At any rate, when it was over, he flung off his surplice, and hurried back to his study, and, to his great delight, he saw Venus just coming on to the Sun. So Horrox and his friend, Crabtree, a weaver, whom he had told of the great event, were the first to see a Transit of Venus. Horrox was quite a young fellow, and I am sorry to say that he died at the age of only 24. He had done so much before 24 that some people think that

if he had lived he might, perhaps, have been an even greater man than Newton.

We see that our Voyage in Space will take us over big distances; 240,000 miles to the Moon, and 93 million miles to the Sun. It hardly seems worth while in starting to bother about the first few miles. But perhaps you have noticed, when you have taken

Horrox observing a Transit of Venus for the first time.
See Notes to Illustrations.)

a railway journey, what a long time it takes to get out of the station; or if you take a voyage on a ship, what a business it is getting out of dock. Afterwards when the ship has started the voyage becomes rather uneventful; but at any rate the first bit is not uneventful. So I think for a few moments we might think about the air through which we must first ascend, and which corresponds to the dock from which we start for a sea voyage.

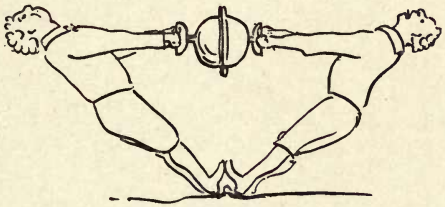
There is one property of the air that seems very

remarkable to those who have never thought about it before. Here it is all around us. It does not seem to be exerting any pressure and yet it is pressing on us all with tremendous force—15 pounds to every square inch. We are all supporting that great pressure, both inside and outside. If we had not the pressure outside, I suppose we should burst; and if we had not the pressure inside we should go flat. We can easily prove there is that kind of pressure by one of those old experiments which I think every generation ought to see, though it has been performed many times, and was first done many years ago: viz. the experiment of the "Magdeburg Hemispheres." We take two cups or hemispheres that are easily pulled apart when there is air both inside and outside. But if we fit them together, and if Mr. Heath kindly connects up the exhaust and takes all the air from inside, they do not, indeed, go flat, because they are made of good solid brass, but we shall find it very difficult to pull them apart.

Now the air is sufficiently exhausted, and I want two very strong men from the front row. Mr. Heath and I will stand behind them in case by some accident the air is not all out and they come apart too easily. But you see it is all out, and though these strong giants are pulling as hard as they can, they cannot separate them. Even when Mr. Heath and I help them we cannot do it. We will now let the air in; and you will see it is as easy to pull them apart as it was at first.

We need not always use an air-pump to get rid of air. Sometimes one can get the air out from between one's hands by squeezing them tightly

together, and there are people who can make a fascinating noise in that way. I have here two beautiful planes, that Mr. Whitworth told us how to make; they fit one another so closely that we can exclude the air without a pump. We must not merely put them together in the ordinary way; we must slide one on to the other in order to squeeze out the air: and then you find them stick so that they are as hard to pull apart as the Magdeburg hemispheres.



TRYING TO SEPARATE THE TWO "MAGDEBURG HEMISPHERES"

These two experiments show the enormous pressure air has. But that is only near the Earth; as we go up it gets less and less; or, perhaps, a better way to look at it is that as we come down in the air the pressure gets greater, because every layer has to support all the layers above it. Fig. 18 is a picture of a totem-post in the Oxford Museum, kindly made for me by a member of the audience and her mother. It used to be outside the tent of an Indian chief. There is a raven at the bottom, and on that a bear holding a hunter; then another bird; above that another bear hugging

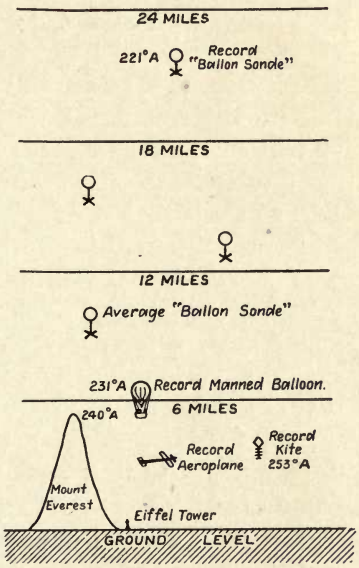
Fig. 18.

Fig. 19.

a hunter. I believe the idea is that when a tribe conquers another tribe they take their totem and put their own on the top: and then again, if that tribe is conquered, the totem of the conquering tribe is again put on top. Now obviously these animals are strong and solid, so they can bear all that weight upon them without getting squashed. But the air is not like that. The air beneath gets squashed down by the air on top. So it would be like the second picture (Fig. 19), when the raven gets squashed flat by all the weight it supports: and even the bear above it gets very much flattened. That is how our air gets treated near the Earth. But high up it gets thin like the chief on the top of the second picture, because there is nothing to squash it. The air is not of course divided into separate layers, as the totem-post is divided into separate animals, but it will do no harm to

treat it as though it were, in thinking out what happens.

Let us make believe that there are different layers, as in Fig. 20, copied from a beautiful picture at the Meteorological Office at South Kensington (which you ought to visit some time, because you will find all sorts of interesting things there). The first layer takes us about six miles up, and may be called the layer of mountains. The highest mountain in the world (Mount Everest) reaches just about to the top, and you see how small the Eiffel Tower looks beside it. The highest aeroplane record is about four miles, so that the first layer is also that of aeroplanes. A kite has been up a little higher than that. And a man in a balloon has actually been just into the second layer, but only just. So that our human experience of the air is practically confined to the first layer, and we knew nothing about the layers above it till quite recently. All our knowledge of them is due to the use of balloons, rather like toy balloons,



IMAGINARY LAYERS OF ATMOSPHERE.

Fig. 20.

though larger. There is one hung up near the roof; perhaps we can get it down at the end of the lecture. These balloons do not carry men, they only carry apparatus; but this apparatus is so skilfully made that it brings down for us information about these upper layers. We learn that the pressure gets less and less, as we expected; but we also learn something that we did not at all expect. We thought that it would get colder and colder as we went higher, but these " sounding-balloons " (*ballons sondes*) tell us that soon after we leave the first layer it ceases to get any colder. The figures for the temperature in Fig. 20 show that it does not get very much colder. They are measured from what we call absolute zero. You know well the ordinary thermometer which your mother puts into your mouth when she thinks you " have a temperature." If we used that we should have to alter these figures a good deal: and if your mother used the one the Meteorological Office uses, I fear she would get a great fright, for she always hopes to find your temperature below 100°, doesn't she? Yet with this thermometer she would find it over 300°, even if there was nothing the matter with you at all. But, of course, if she were warned beforehand that that was the proper temperature for you to have with this kind of thermometer, she would not be alarmed: there are such various kinds of thermometers, that before using any of them it is well to know beforehand what to expect.

Well, the great fact we have recently learnt about these upper layers of the air is that the temperature ceases to fall in a way that has been a great surprise

to us. The sounding balloons have gone up higher and higher until they burst, and then the apparatus carried by them falls down to the ground. You might think it would get hopelessly smashed by such a fall (from a height of 20 miles, say), but the burst balloon case acts as a kind of parachute, or drag, so that the blow on the ground is not really so very hard, and also the apparatus is attached to an ingenious light framework called a "spider," which eases the blow still further: so that usually it is not damaged, and not only does it tell us what happened to it in the upper layers, where man has never reached, but it can be used again and again to get more news. The news has been of intense interest to scientific men, but would scarcely interest us enough to justify dwelling longer on it. Rather, let us return to the bottom layer and recall a few things which have happened in it.

Let us begin with the mountains. Many people have ascended mountains and got above the clouds. In order to get above the clouds they have put a magnificent observatory on Mt. Wilson in California, 6000 feet above the dust, which can also be seen lying below them. Astronomers have begun to use mountains not only to get above dust and clouds, but because they also get above a considerable amount of air. Professor Campbell went up Mount Whitney, sometimes called the "top of the United States," to make observations upon Mars, especially to see whether it has an atmosphere containing water vapour. He made his arduous expedition in order that he might not mistake for water vapour in Mars what really belonged to our own Earth. Having

much less of our own air between him and Mars, he was less likely to make that mistake. He concluded that there could not be very much, perhaps not more than on the Moon, which we know to be very dry indeed. He lived in a desolate little hut on the top of Mount Whitney for a considerable time to make

Merry Christmas
1913

Elizabeth B Campbell
W. W Campbell

these observations, but usually he lives on the top of a more comfortable mountain (4000 feet high) at the Lick Observatory. I got a pretty Christmas card from him, showing the Lick Observatory in winter with the snow on it, which I am sure he would like me to share with you. The snow is, of course, only there in winter, and rarely even then; generally the Lick Observatory has a beautiful summer climate. But there are mountains, as you all know, on which

there is perpetual snow, and yet climbers of mountains have gone up even higher than aeroplanes have gone. But I am sure you are much more interested in aeroplanes, because to go in one seems more like leaving the Earth behind; whilst we are on a mountain we are still touching the Earth. Aeroplanes are becoming so common that we have nearly forgotten how hard it was to invent them, and who did the early pioneer work which led to the invention. Who first thought of the name " aeroplane "? When you want to find out a thing like that, one good way is to look in the dictionary: and I hope you all look in the dictionary when you want to find out things, instead of bothering other people with questions which they cannot answer. But if one wants to be sure of getting the right answer, an even better way is to bother the man who makes the dictionary: and we are fortunate enough to have in Oxford Sir James Murray,[1] who is making a very big dictionary, and who was able to tell me a curious thing about aeroplanes. First of all, the word means *a plane* used for experiments on *air*. That is the way he has defined it in his dictionary, of which the letter A was published in 1888 (though they have not yet got to Z !). He says the word was then used in England to mean " a plane placed in the air for aerostatistical experiments." But he also says that " aeroplane " was used in France in quite a different way; *plane* meaning there not a plane surface at all, but a thing which soars. Those who know French will know that they use the word " planer " to mean soaring

[1] Sir James Murray died while this book was in the press.

like birds. I am sure you have all heard of a "vol plané," which means a soaring flight. And these two different ways of using the word may be illustrated in this way. A piece of paper like this is a *plane:* and we might put it at the end of a mechanical arm, and find the amount of pressure on it when it is moved about. Several such arms or sails put together would make a toy windmill: and, although that is scarcely a piece of scientific apparatus as it is usually made, a very little alteration would make it into one. In the toy, all the sails are set at the same angle, and they blow round merrily. But suppose we set some one way and some another, so that they want to go round in opposite directions, we could balance them so that the machine would turn neither way, however strong the wind was, and now we have a piece of scientific apparatus. Lord Rayleigh made many experiments with a simple machine of this kind, like a toy windmill, of which he could put the vanes at different angles. I think there were six vanes, and he set two of them in one direction and four in the other, but at a different angle, which he chose, so that the two would balance the four, and then the machine would not go round at all. By varying these angles he learnt a great deal: and the plane sails of his apparatus were aeroplanes. But I can take the same piece of paper and make it into another kind of aeroplane—a thing which soars; you probably know how to make this kind of dart, which soars about. That is a different kind of aeroplane, like those in which people fly. Here is a beautiful little model of an aeroplane that has been kindly lent from the Grahame-White Company. It was the

prize at one of the Hendon Race Meetings, I believe. And the same company have kindly lent a few slides, which I am sure you will like to see. You are regularly spoilt children, because every one seems so ready to lend things to be shown to you.

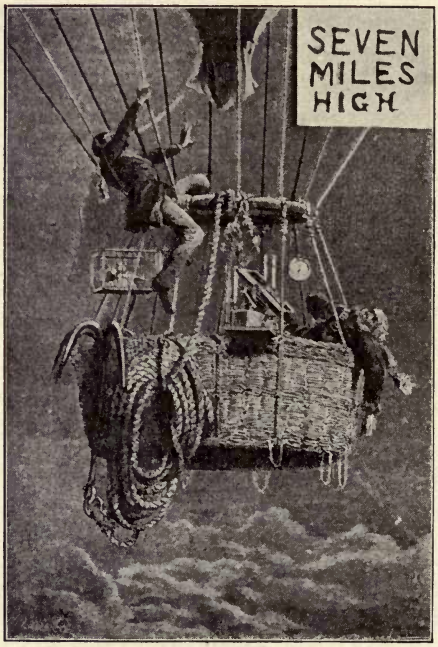
When we went over to America in 1910 to have a meeting of astronomers who study the Sun—the modern Sun worshippers—I was lucky enough to see a great aeroplane race meeting : and it was specially interesting to see Mr. Grahame White dropping chalk balls to try and hit the funnels of an imaginary ship marked out on the ground. It was quite difficult to hit the funnel from 100 feet up, when travelling at full speed, and of course an aeroplane would have to fly much higher up in time of war to avoid being shot at. So at the end of the meeting Mr. Grahame White kindly volunteered to try from a much greater height —1700 feet, I think. A hard chalk ball falling from this height might by accident hurt some one badly, so in this instance he dropped eggs, and presently a man came out with a megaphone to say what the result was; and he said something like this—

MISTER—GRAHAME—WHITE—HAS—DROPPED—ELEVEN—EGGS—FROM—SEVENTEEN—HUNDRED—FEET—BUT—THE—UMPIRES—HAVE—NOT—BEEN—ABLE—TO—SAY—WHERE—ANY—OF THEM—FELL.

You can well believe that the crowd laughed at this odd result, and it was suggested that the eggs hatched out on the way down and flew away!

Here you see that wonderful modern achievement called looping the loop. But, with all our admiration for aeroplanes, we must not forget that in the old days

balloonists did some extraordinarily plucky things. There is a fascinating book about ballooning called *Travels in the Air*, by James Glaisher,[1] but I fear it is now out of print, so that your only chance is to find it in some library. It has beautiful pictures of the



balloon travelling above the clouds, with wonderful sunrise effects. Sometimes the balloonists saw their own shadow thrown on the clouds : and on one occasion, in 1866, they saw a great shower of meteors. But the most exciting occasion was when they got

[1] Bentley, London, 1871. New edition, 1880. Price 25*s*.

nearly seven miles high and nearly died from the cold. Mr. Glaisher himself fainted: his companion, Mr. Coxwell, wished to open the valve so that the balloon might descend, but found that his hands were frost-bitten: however, he managed to climb up with his elbows and knees and open it with his teeth, and then they dropped quickly to a warmer region and revived. Mr. Glaisher's object in making these ascents was to find out the temperature and pressure of the upper air, for which purpose he carried up a whole trayful of instruments: and he did find out a very great deal—practically all we knew until recent times. But since seven miles was the highest he ever went, we knew nothing at all about the air above that point. We could only guess, and we guessed quite wrong.

And now we come to the balloons that have really taught us about the upper air, about which the people who study the weather have been trying to learn for years, and have at last succeeded. First of all they tried by sending up kites of a peculiar shape: you see a fine specimen up there. They are not like ordinary kites, but are in the shape of a box almost; but they have been copied in the form of toys, and perhaps this one does not seem so strange to you as it would have to us in our childhood. These kites can be got up to great heights by attaching one to another in a series. The top kite has been up above the aeroplane record, but not so high as the man-balloon record. They do not, of course, take up men with them, but they carry a recording apparatus, including a barometer and thermometer. The thermometer is that curious spiral spring at the back·

All these things write their own story on this piece of paper in front. I wonder if you can guess what is the use of that ping-pong ball tied to a thread? It tells the force of the wind, because the wind blows the ball away from the kite, so that it pulls the string, and the more it pulls the more it writes on this diagram. Then presently the kite is hauled down, and this diagram is read; and from this we find out what has been going on in the upper air. When these kites are up miles high, the pull on the wire (they use wire and not string) is tremendous, and special machines are necessary for winding the wire.

But lately it has been found better to use balloons instead of kites; balloons filled with hydrogen, which is so light that it takes them up for miles and miles before they burst. They always burst at last, because the pressure of the air outside keeps getting less and less as we go up (you remember how we illustrated that with the totem-post pictures), but the hydrogen inside does not get less, and so swells the balloon out more and more. I told you that if there were no air outside us, we might burst; and that is actually what happens to the balloon when it gets so high that the air outside it scarcely presses it at all. And then down it comes like a parachute, bringing the precious records, like those attached to the kite. But of course the kite is pulled down gently and smoothly by means of its wire, whereas the balloon-case drops from a great height, and it is important to prevent a jar on reaching the ground which might damage the instruments which make the records. They are costly, and must be used again and again if possible. Accordingly the

instruments are made of very light materials; and, as already mentioned, they are attached to a light framework called a "spider," consisting of three bamboo rods tied together, at their middle points, and set each one at right angles to the other two. To keep them in this position their ends are joined up by thin strings, the whole forming a framework which is very strong for its weight, and which may fall on any part of itself without much damage. The precious apparatus is securely fixed to the very centre of this framework, so that when the balloon drops, it falls always on its feet so to speak. You know how a cat prevents its body being hurt when it falls by twisting in a remarkable way so as to fall on its springy feet? Well, we cannot provide the apparatus with the agility of a cat, so as to make its feet twist under it; but the "spider" has feet in all directions, which acts just as well. Make a "spider" for yourselves when you get home, and see how strong and light it is. Here is a miniature "spider" which Mr. Bellamy has kindly made out of three bits of straw and some thread; and it is so light that even a toy balloon will carry it up if properly filled with hydrogen. We will make the experiment. There! you see; up it goes! It cannot rise high enough to burst in the proper way because the roof stops it; but fortunately Galileo is still up there in the roof, or has gone back again, and he can arrange the bursting for us; and down come the case and spider and all! One very important thing I had nearly forgotten. The spider may fall anywhere—perhaps far away from any town or people. Who is to find it, and send it home? It stands well above the

ground and can be seen from some distance, so that it is not long before some wanderer finds it; and he also finds a label attached to it, saying that if he will send the apparatus and records to the Meteorological Office he will get five shillings reward. I am sure five shillings would be very useful to many of you, so I advise you to keep a sharp look-out whenever you are in the country to see whether you can find a "spider," and get the five shillings reward.

There is one thing about the upper atmosphere which these sounding-balloons do not tell us, though if they could bring down some of it they might; and perhaps it may be arranged at some future time that they shall bring samples down with them, and then we should be able to verify what we believe to be true, viz., that certain gases, which are present in our lowest layer in very minute quantities, become much more common up there. When I was a boy, we were taught that the air consisted of oxygen, nitrogen, carbon dioxide (or carbonic acid gas, if you like that name better), and water vapour; nothing else but these four. But in the year 1894 Lord Rayleigh announced to the British Association, which was then meeting at Oxford, that he had found something else in the air—a gas so like nitrogen that he had had the utmost difficulty in separating the two, but clearly different from nitrogen when sufficient care was taken to divide them. It was a most exciting announcement, because we all thought that we knew practically all there was to be known about the nature of air, and it was a great shock to find that we were all wrong. The new gas was called argon; and soon other new gases were found, especially by

Sir William Ramsay—helium, and neon, and xenon, and a heap of others; so that unfortunate schoolboys, instead of having to learn only four things as making up air, as we did, have now to learn a large number of names. Life has a terrible way of getting more and more difficult!

Well, now, one of the reasons why these gases were not found before is that down here in the lowest layers they are very scarce, like rare butterflies, such as the Camberwell Beauty, which is very hard indeed to find in England. But if you go abroad, you may find Camberwell Beauties by no means uncommon. So also, if we could go "abroad" into the upper air, we might find these rare gases much more easily. And there is one thing about them that will interest you, I hope, though their names may be tiresome to learn; they give very pretty colours when we electrify them. We have a series of tubes here filled with specimens of various gases, and when we pass a current through them you will see their different beautiful colours.

There is one other way in which we learn about the upper air, and that is through those meteors, which you saw on one of the balloon slides. A meteor, or, as it is often called, a shooting star, is a bright light like a star that darts across the sky; but it has nothing to do with stars; it is only a piece of stone or metal. Here are some meteors and fragments of meteors; many of the shooting stars you see would be much less than any of these; tiny specks so small that they get burnt up entirely. What makes them shine and burn is the friction of the air as they rush into it. You have heard of producing fire by rubbing two pieces of wood together?

The faster you rub the sooner you get the fire. It is not at all easy to make the fire because it is not easy to rub fast enough; but a meteor rushes into the air at a great speed, fifty miles a second at least. It seems to us a great speed when our motor-car goes at 50 miles an hour; think what it must be to go at 50 miles a second, nearly 4000 times as fast as a motor-car! I am afraid the police would not allow us to try it; but if we could increase the speed more and more, we should find that the air which at first gently blows us cool, was becoming a fierce wind; and presently, instead of being at all cool, it would seem hot; and long before we reached the speed of a meteor t would be unbearable.

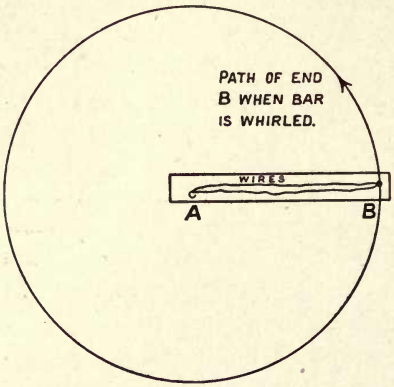


Fig. 21.

It may seem surprising that anything so soft and thin as air can produce the same effect by friction as we get from hard wood, but we can actually prove it by experiment. Sir James Dewar devised this ingenious apparatus to do so (Fig. 21). A wooden arm AB can be spun about the end A. The end B thus rushes at a considerable speed through the air—not the speed of a meteor, or anything like it, but still a sufficient speed to be heated by friction. The heating will not be very great, but I think we can detect

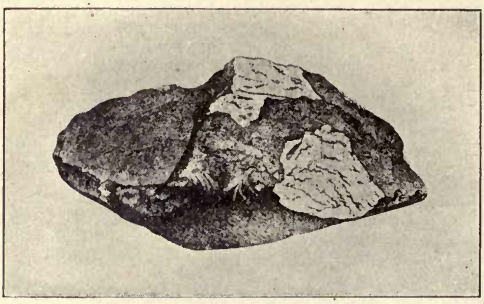
it and even show it to you on the screen; and the method is this: we join two wires of different metals at both ends, and put one junction at the end A of the spinning bar and the other at the end B. Now it is a well-known fact that if one of these junctions be heated more than the other, an electric current will flow in the wires, which we can detect by using this galvanometer. You see that spot of light on the screen? Well, when an electric current flows it will move to right or left; and we want to know which way it moves when the end B is heated. Perhaps one of the ladies in the front row will kindly put her cheek against the end B for a moment. There goes the spot to the right, showing quite a warm cheek! (Perhaps that is better than a cool cheek?) Accordingly we know that if the end B gets warm, the spot will move to the right. Now we will buzz the arm round as quickly as we can, and there goes the spot to the right again, showing that the junction B is heated by its rushing through the air. The end A, you see, is so near the centre that it remains practically stationary.

If we could whirl the arm round ever so much more quickly we might heat the wire so much that it would shine like a meteor, and perhaps be burnt up; but you will easily understand why I cannot do this.

Some meteors, however, are too big to get burnt up. They come right through the air and bury themselves in the ground, as you remember the leaden ball buried itself when Galileo dropped it from the roof. I hope you will never have the ill-luck to be hit by a meteor, for it would hurt much worse than any bullet. Once a monk was sleeping

in a tent, and a meteor went right through tent and monk and bed below him, and buried itself deep in the ground. But that is the only case I ever heard of where any one has been struck in this way, because meteors are very rare. Mr. Gregory has been kind enough to lend us his wonderful collection for you to look at, and I hope you will look carefully at them after the lecture.

Before a meteor enters our air it is travelling



The Gross Divina Meteorite.

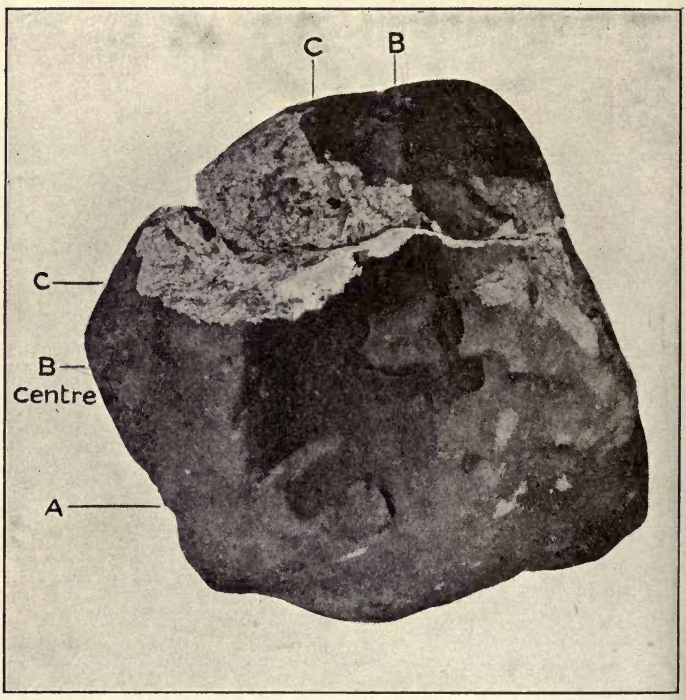
through the terribly cold regions of space, and is chilled to its marrow. When it rushes into our air it becomes heated as we have said; but it travels so quickly that it comes right through the air in a few seconds, and though the outside gets very hot, there is not time for the heat to get inside. The inside remains just as cold as it was before, and only a thin coating near the surface is heated. When the meteor comes to rest in the ground, the heat of the crust is soon overcome by the bitter cold of the inside; and in a very few minutes the crust which was so hot as to be shining brightly is so cold that hoar

frost settles on it; and in this state meteors have often been found by those who have seen them flash down, have marked the spot where they fell, and hastened towards them as quickly as possible. Mr. Gregory has kindly cut some of his meteors so that you can see where this thin outer crust stops; you see how very little had time to get heated; all the inside remained cool.

Here is a specimen which should be of particular interest to the ladies present, because it has diamonds in it: not very large ones, but still unmistakable diamonds. Mr. Parsons (whom you all know, I hope, as the inventor of the turbine) tells me that he thinks these diamonds are made when two meteors strike one another. I have told you at what fearful speeds they travel, 50 or 100 miles a second, say; and if two of them hit, the pressure developed must be enormous, far greater than anything we can imitate on this Earth. And Mr. Parsons further tells me that he believes all diamonds are made in this way. He has himself tried many times to make diamonds without success, and he thinks it is because he cannot get pressures nearly big enough; and so he inclines to the view that all the diamonds we find have been brought to the Earth by meteors which fell on it in ages past. This makes us look with increased respect at Mr. Gregory's collection, doesn't it?

But diamonds are not the only substance meteors have brought us; shut up inside them various gases have been found. Where were these gases collected? Probably in the upper layers of our own atmosphere. You remember how we regretted that the sounding-balloons were not able to bring us down samples of

the air up aloft? Well, fortunately, meteors are able to do this very thing to a limited extent. In their fierce rush they catch the gases and shut them up



The Appley Bridge Aerolite, Oct. 13, 1914. Scale $\frac{1}{3}$.
(See Notes to Illustrations.)

inside themselves so that chemists have been able to get them out afterwards and find their nature. They have often found hydrogen in this way inside meteors, and so we learn, what can be shown to be probable in other ways, that there is a good deal of

hydrogen in the uppermost layers. Unfortunately these gases often escape before the chemists can get at them; they burst through the outer covering. In some of Mr. Gregory's specimens you see the holes through which the gases have burst out before we could examine them.

In one way and another, therefore, we have learnt a good deal about the upper air lately, so that we know what we should have to pass through in leaving port when we start on our voyage. The air will get thinner and colder and change ultimately into hydrogen, and then—what after that? We shall get out into the cold and silence of space—the great Silence. Perhaps it had not occurred to you that we should lose all sensation of sound? Our ancestors thought that the heavenly bodies were making beautiful music—the "music of the spheres"; but there is nothing to carry music in space. Most sounds we hear are carried by air; though they can be carried by other things as well. Here is a wooden rod which goes down through the floor into the basement where there is a musical-box. The sound of the music is coming up this rod into this room, though only those close to the rod can hear it, even faintly. But if two of my audience will kindly lift this wooden tray on to the top of the rod, the tray will act as a resonator and the whole room will hear the musical-box through the instrumentality of the rod. (Experiment as indicated.) So that materials other than air can carry sound. But in outer space there is no material at all, not even air; so that no sounds can travel. We can realize this by another experiment with this bell,

which is ringing plainly enough even when I cover it with a glass jar. But now, if we exhaust the air from the jar the sound will die away until you cannot hear it at all, though you can see that the hammer is still striking the bell as vigorously as ever. (Experiment.) And if we gradually let the air in again the sound comes back. All the apparatus for making the sound was the same throughout; only the air which carries it was removed, and the other materials round (such as the table) did not carry it sufficiently for you to hear.

Hence we must be prepared for a great silence on our voyage. When Jules Verne's travellers were shot out of the enormous cannon to the Moon, they were puzzled because they did not hear even the sound of the explosion which started them; and they reasoned it out that they travelled more quickly than sound, so that the sound was unable to catch them up. Of course, they talked to one another inside the projectile because they took air with them; but they were cut off from all outside sounds. Other projectiles might have blown foghorns louder than any steamer that ever passed us on the sea, but the warning would not be of the slightest use because it could not be heard.

It seems almost better for us not to venture into this great silence, doesn't it? Especially if I am to continue these lectures. You will not be able to hear me if we have no air, for several reasons. Consequently I shall next time propose a method of making our voyage which will avoid this difficulty, and allow us to stay comfortably in this room all the time.

LECTURE III

JOURNEYING BY TELESCOPE

We may now consider that we have properly said good-bye to our old friend the Earth, who attracts us in more ways than one; we have also looked at the station or port, and it is really time to be starting. We must seriously choose our carriage and get into it. What kind of a carriage is it to be?

We saw last time that an airship or aeroplane can only take us a very little way—six or seven miles at the most—and we want to go much farther than that. Jules Verne chose to shoot a great projectile holding three people, which went as far as the Moon; but then he had to start it with great velocity, and it was only his enthusiastic imagination which enabled the travellers to survive the shock. Mr. H. G. Wells had the happy idea of screening out gravity by a newly discovered substance called Cavorite (in honour of its inventor). For that purpose blinds were fitted to the windows of the "sphere" that he mentions in his fascinating book; and so this "sphere" was enabled to float, or move in some indescribable way (because we are so accustomed to gravity we do not quite know what to call movement without it) as far as the Moon. It might have gone even much further, without difficulty or inconvenience, except

that it would almost certainly have taken a long time; and we want something to go much quicker than that sphere. It accordingly occurred to me that we could not do better than adopt a hint from our old friend Mark Twain in his *Tramp Abroad* (a delightful book which can be bought for sevenpence nowadays). Perhaps you have read it, and you remember that after he had braved the perils of the ascent of the Riffelberg (which had taken him seven days !), he was contemplating going up Mont Blanc. But the perils of the actual ascent seemed so great that he decided to make it by telescope. He found in the village street at Chamonix a man with a telescope directed on a party going up the mountain; he followed them up by means of that telescope, feeling all the time just as though he were along with them; so that when they had got to the top, he quite felt that he had got there himself, and cheered so loudly that he disturbed the people round and they made remarks which called him back to Chamonix.

The advantage of going by telescope is, first of all, as Mark Twain hints, that it is very much safer. I am afraid I have not got a licence to drive an aeroplane, and if I had I might even then have an accident. But besides being safer, the telescope takes us much more quickly. Supposing you wanted to get to the Sun, even in two years, how fast do you think you would have to go? We said the Sun is 93 million miles away; and there are about a million minutes in two years; so that you would have to go about 93 miles a minute—which is pretty quick ! But we can go much quicker than that by telescope. We can get to the stars, I was going to say, in *no time;*

but it is really *less than no time* because we shall get there before to-day; we shall see things happening not to-day, but many years ago; just as when abroad you get a newspaper not of to-day, but of yesterday or perhaps a week before; and thus you learn what your friends were doing yesterday or a week before. Now, although light travels very quickly, it takes time to travel; and the light that comes to us from the distant stars tells us what happened years ago, perhaps thousands of years ago; and this gives one a very curious feeling when we reflect upon it. When we were little babies and went out for our first walk, and saw the sky for the first time, some of the light which fell upon us went back towards the sky and part of it enabled our nurse to see us. Unless the light did come back from the baby in that way, the nurse would not see it. But she did not use up all the light from the baby; another part of it went on past the nurse, perhaps into the telescope of an angel (if angels have telescopes), and then the angel saw the baby; but not till some time after the nurse had seen it, because the light would take time to get from nurse to angel. And another part of the light which missed the nurse and missed the angel would perhaps go on to a star; but it would only get there after some years. Now if you could be put in one of those stars *immediately*, and if you had a powerful enough telescope, you might be able to see yourself as a baby going out for the first time; because the light would not have got there immediately, but would have taken all the years you have been alive to get there. If you went on to more distant stars you might (*if* you had a strong enough

telescope; it is a large IF), you *might* see your grandmother going out as a baby for the first time.

Well, as I say, that means that if we use the telescope, we shall get to the heavenly bodies in really less than no time, which would be very convenient;

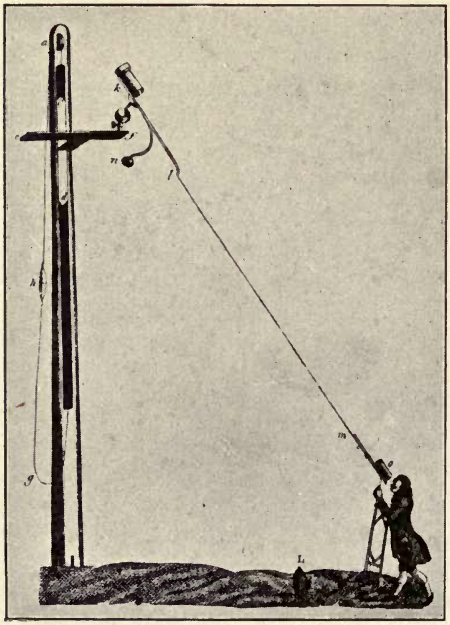


Fig. 22.

and so I propose to say a word or two about this wonderful car we are going in—the Telescope; for it is just as well to understand your car. Any one who gets a motor-car looks carefully at all the parts; and to-day I want you to learn about the telescope, and what has been its history. Perhaps I ought not

to say *telescope*, but *camera*, for most of the telescopes astronomers use nowadays are just photographic cameras on a large scale. So we might say that we will journey by *camera*. But in its early history the telescope was not a camera, and so we will for the present use the name *telescope*.

The earliest telescopes of any importance were very long and thin. Perhaps you will hardly recognize that object in Fig. 22 as a telescope; one end is high up in the air and the other is down on the ground. Sometimes these telescopes were 200 feet long, and they must have been extraordinarily difficult to manage. The astronomers who used them, and really got very accurate results with them, must have been men of great skill. Why did they make them so terribly long when we in modern days have been satisfied with much shorter telescopes? The reason was that they were bothered by *colour*. We shall see how colour comes into the question in a few moments when we do some experiments; and we shall also see how colour is now a positive advantage to astronomers, when properly used; but in those early days it was only recognized as a disadvantage which drove astronomers to make their telescopes so long and thin that they became difficult to manage. In Fig. 23 is a way of making a long telescope, suggested by the great astronomer Hevelius; he was very proud of his invention and wrote a book about it; and the whole invention was that you need not have an actual tube for the telescope (made of four planks, like a long thin box; that was the way some of them were made), but that a single plank would suffice, if only a lot of circular diaphragms were attached to

the plank at intervals. His whole invention was to save three of the four planks and use one only! Perhaps I am not quite fair, for he was also rather proud of his invention of the lifting gear and of the floor under which the telescope could be stowed when out of use.

You will readily see the great difficulties of using

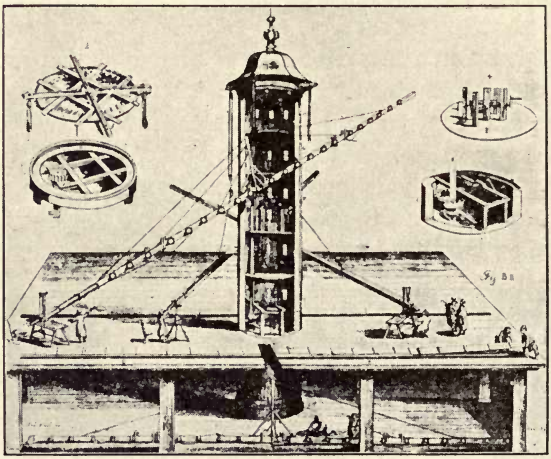
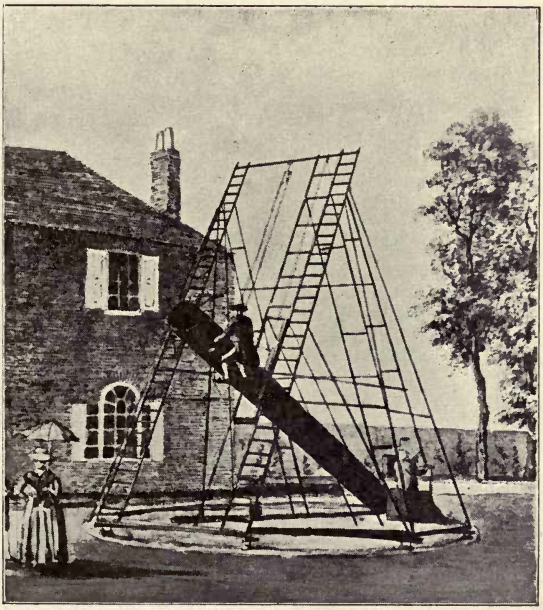


Fig. 23.

these machines, so that astronomers cast about for some other way of getting over the difficulty of colour. It occurred to several people independently that if a mirror could be used instead of a lens to bring the light to focus there would then be no colour and therefore no difficulty. We will explain this fact and illustrate it by experiment in a few minutes; but first let me say a word or two about the consequences of this new move in the making of

telescopes. They were made with mirrors—reflecting telescopes, as they are called—and they ceased to be so very thin. Indeed, on the contrary, they became quite fat, for there is a great advantage in having the mirror as wide as possible : you can see



W. Herschel at his great Telescope.

much more clearly with a wide telescope than with a narrow one, always assuming that the wide one is just as well made. But it is much harder to make a big wide mirror than a little one, just as it is harder to get 100 runs at cricket than to get ten; the batsman may play several overs successfully, but he has to be terribly careful not to make a mistake if he

wants to make 100. So with mirrors; it may be easy to make a little one without any mistake, but it is awfully hard to make a large one without some flaw in it which prevents it being a good mirror. The first man to get a century, so to speak, by making a really large mirror without flaw, was William Herschel, who did not begin to try until he was 37 years old. As a boy he was in the band of a Hanoverian regiment, like his father and several of his brothers. It is sad that we cannot claim Herschel as a born Englishman, but he settled in England and got a position as organist at Bath. He showed some cleverness in getting that position, but scarcely of a kind to suggest the wonderful work he was to do in astronomy afterwards. The story is that when the different candidates for the post of organist were being tried, one of them played so skilfully that a friend remarked to Herschel that it was scarcely possible to play any better. "I don't think fingers can do it," agreed Herschel. Nevertheless he went up into the organ loft and produced such astonishing effects that the judges awarded him the post. The same friend, who had shared in the general astonishment, could not help asking how in the world he had managed to play as he did; whereupon, with a twinkle in his eye, Herschel produced from his pocket two leaden discs, and said, "You remember I told you fingers alone could not beat the playing we had heard; but I put these discs, one on a low note and the other on a high note, leaving my hands free for the middle, and in that way I managed to surprise you." After all, though the trick may seem a simple one, it must have required great skill to use it to full

advantage; I expect only a remarkable man would have thought of it. And presently Herschel showed much more clearly how remarkable he was. He became interested in the making of mirrors almost by accident; but once started, he went on from one success to another. I have compared making a big mirror to getting 100 runs; and it required quite as much watchful care on Herschel's part. His innings at polishing went on for long hours—sometimes twelve hours at a stretch, with no intervals for meals. All the food he got was put into his mouth by his sister Caroline, while he still went on polishing. She was a splendid sister to him—took down notes of what he saw through his telescopes when he had made them, and wrote them out neatly for publication; and when he was not using his telescopes, Caroline would use them herself, and she found several comets in that way. William Herschel worked very hard, but Caroline worked just as hard in helping him; and whenever the brother is mentioned with honour, I think the sister ought to be mentioned also. The greatest thing William Herschel did was to discover the planet which we now call Uranus, though he himself wished it called Georgium Sidus, after King George III, who had given him much encouragement. Other people wanted it called

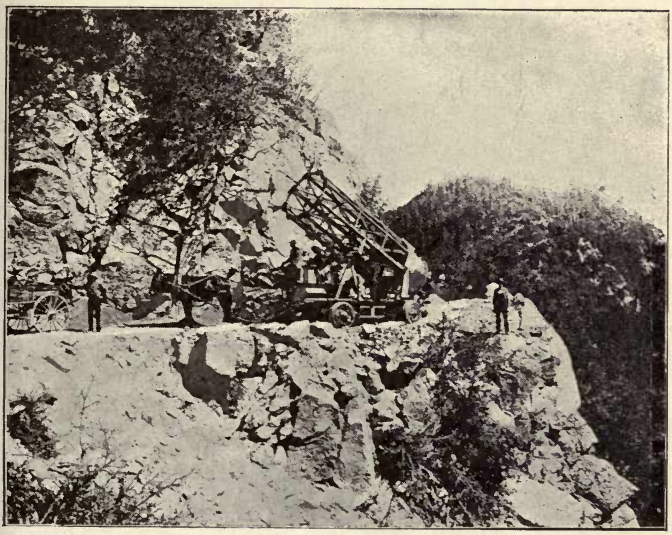
Caroline Herschel.

Herschel, in honour of the discoverer, and both these names were used for many years. But still other people said that for anybody to have his name attached to a planet was far too great an honour, whether he were discoverer or king; and ultimately these got their way by establishing the name Uranus.

Herschel's largest mirror was four feet wide; but afterwards Lord Rosse made one six feet wide, which is, up to the present, the largest telescope ever made. A man could stand in the mouth of it. The making of the mirror itself was a great achievement, but that was by no means all; to fit it into a telescope that could be easily handled was a triumph of engineering skill and could only have been accomplished by a great engineer such as Lord Rosse was. One of his sons is also a great engineer; he is the Mr. Parsons who invented the steam turbine, and made a success of it in spite of enormous discouragements; and he told us, you remember, about the diamonds in meteorites.

Herschel's four-foot mirror and Lord Rosse's six-foot are still in existence, and the latter is actually in use in the telescope, though the former has been dismounted. But the surfaces of both have become tarnished, so that they no longer show things clearly. They are made of a peculiar kind of metal called speculum metal, which remains bright for some time, but gradually tarnishes in the course of years in a manner difficult to remedy. To avoid this gradual deterioration, mirrors have been made recently of glass which is then silvered with a thin film on the front surface. This film also tarnishes after

a time, but it can easily be removed with a little acid, and then a new bright film can be put on so that the mirror is as good as new. A good many mirrors two or three feet wide have been made in this way; but the first really big one was made by Dr. Common at Ealing. It was five feet wide, not so wide as Lord

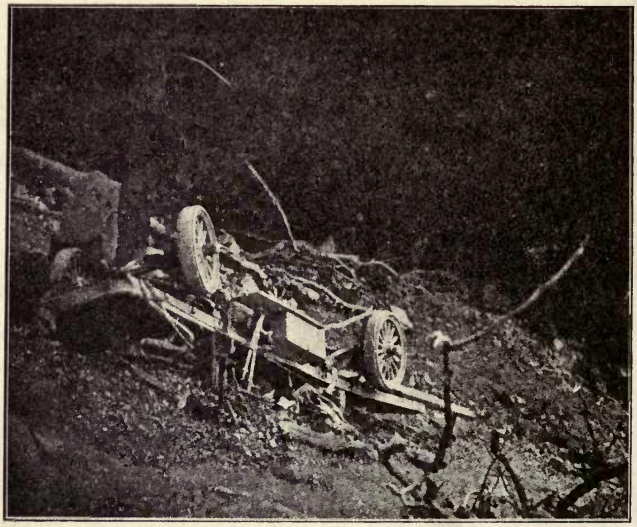


The great Five-foot Telescope being taken up Mount Wilson.

Rosse's (six feet), but still a great advance on any previous " silver-on-glass " mirror. With it he took some wonderful pictures of nebulæ and other objects of the heavens, but he did not live long after he had made it, and the telescope was sold at his death to the Harvard Observatory in the United States.

Since then a five-foot mirror even better than Dr. Common's has been made and set up at Mount

Wilson in California; and it has been so successful that they are attempting a much bigger one still, 100 inches wide, or 8 feet 4 inches. If they succeed in making it, they will have the first telescope to surpass in size that of Lord Rosse. In this case, besides the great difficulties of making the telescopes,



An accident to the traffic up Mount Wilson.

they had the extra ones of getting them to the top of a mountain 6000 feet high, which are by no means inconsiderable. When I first visited Mount Wilson in 1904, the path up the mountain was only three feet wide, with a steep face on one side and a sudden drop on the other; the path was just about wide enough for one mule; but the mules did not think so; they kept trying to crowd past one another,

which is not pleasant for the rider, especially as they try to pass on the outside, where a slip means tumbling down the precipice. Professor Hale had this path widened to five feet all the way before he could venture to send up the big five-foot mirror and its mounting; and I believe it is now being widened further still to twelve feet, so that they can carry up the 100-inch mirror in comfort when it is made. The five-foot has been at work on the top of the mountain for several years, and has taken some most beautiful photographs of objects far away in the depths of space. We will presently put some of them on the screen, and in that way we shall be practically allowing this magnificent telescope to carry us in imagination for a long "voyage in space," such as was not possible a few years ago. But it is a curious thing that when you get to the top of Mount Wilson, the Earth seems almost more striking than the heavens. Down below you in the plains are the two cities of Los Angeles and Pasadena; and when these are lit up at night they make glittering constellations of which the stars are brighter than those in the sky above. (See illustration facing p. 126.)

Having told you something about the history of these big reflecting telescopes—the biggest telescopes in the world—I want to go back and talk a little about the reason for making mirrors instead of lenses: so that the trouble about colour is avoided.

When we make a telescope with a lens we use a property of light called *refraction*, a word from the Latin which means simply *breaking back*. You know how a cricket ball can be bowled so as to go straight

for some distance, and then when it hits the surface of the ground it " breaks back " owing to the spin the bowler has given it? Well, a beam of light behaves in much the same way when it is refracted; after going straight for some distance, it strikes a surface and turns off at an angle.

In Fig. 24 the beam of light AB goes along straight from A to B, and then strikes SF, the surface of glass or water; thereupon instead of continuing straight along BC it is " broken back," or is refracted along BD. Now when we use a lens, we have two

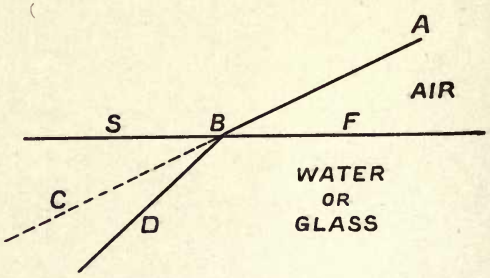


Fig. 24.

surfaces to deal with, one where the light goes in and one where it comes out, and both of these are curved, which is a new complication. To keep matters as simple as possible I will first use a prism; that is, a piece of glass with two *flat* surfaces. When the ray AB strikes the first surface SF (Fig. 25), it is broken back as we have said along BD; and when it comes to the second surface to get out of the glass again it is broken back again along DE. You may think that I have drawn DE the wrong way and that it should have been in some such direction as DX; but

when you try with a prism you will find the ray behaves as drawn; it gets bent in the same direction

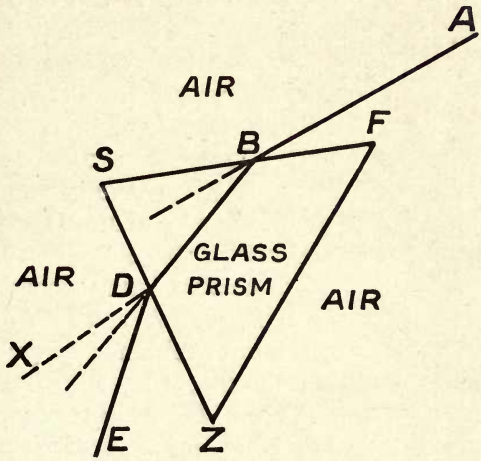


Fig. 25.

both times, and comes out in a line quite turned aside from its original direction AB. But at the

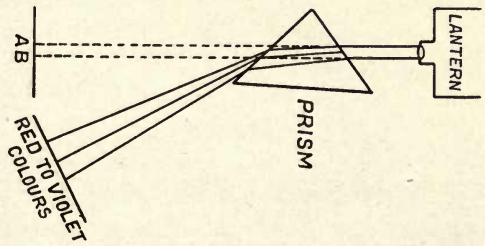


Fig. 26.

same time it becomes coloured, with all the colours of the rainbow. Whenever you get this refraction or "breaking back" you also get colour. When I

put this prism in the path of a straight beam of light it is bent aside so that it no longer falls on the screen in front, but on this other screen to the side; and at the same time it becomes beautifully coloured (Fig. 26). The fact is that blue colours are more bendable than yellow, and yellow than red; so that though all the colours start together in the same ray out of the lantern, when the prism bends them, some bend more than others and we get them separated. Now those colours have become lately of the greatest value to astronomers, but at first they were merely a nuisance; they interfered with the use of lenses in telescopes. A lens is a piece of glass with curved surfaces; when rays of light strike those surfaces they are bent to a focus (Fig. 27), as is wanted for making a telescope. But the bending introduces colour which is *not* wanted; and yet they could not in early days get rid of the colours without also getting rid of the bending to focus. All they could do was to keep the colour effects as small as possible by making the bending also small, which means that the rays have to travel a long way before they come to focus. That is why the early telescopes made with lenses were so long and thin; if they had been shorter and wider the colour effects would have been so great that the observations would have been use-

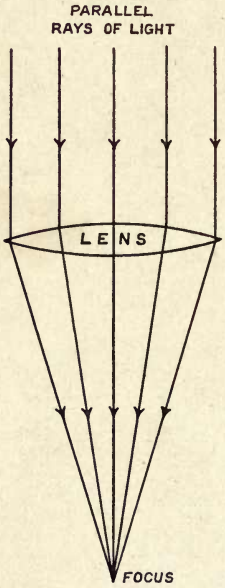


Fig. 27.

less. Newton and Gregory and others therefore turned aside from the making of lenses and proposed to use mirrors, which can also collect rays of light to a focus if they are hollowed out to a particular shape. You can try this for yourselves with the reflector of a common oil-lamp; it will bring rays to a focus just as a burning glass will (Fig. 28).

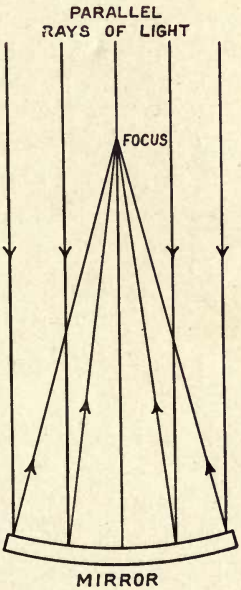
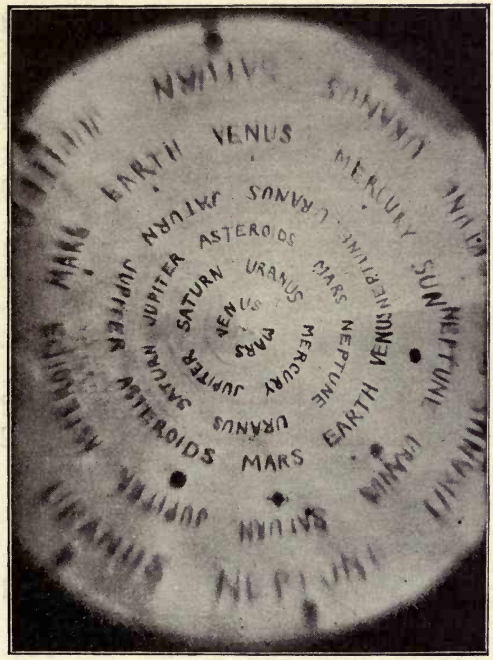


Fig. 28.

But now let me show you another prism. When this is put in the path of the rays you see they are not broken back at all; they still pass straight to the screen; but at the same time they are wonderfully coloured. How is this? We learnt that colour was a result of refraction, and yet here is colour without refraction. The fact is, this prism is really made up of two; one bends the rays aside and colours them, the other bends them back again *without undoing the colour entirely*. That is a new and valuable idea, that one bending can balance another and yet the colour effects do not balance, because it suggests to us at once that we ought to be able to do just the opposite, that is to balance the colour effects and leave the bendings unbalanced; and in this way we can make a lens which will not show colour. When this was once realized astronomers went back to lenses for their large telescopes, and they have suc-

ceeded in making lenses larger and larger until the largest is now 40 inches wide—the great lens at the Yerkes Observatory near Chicago. That is a long way short of the largest mirror telescope (you remember that Lord Rosse's was six feet wide); but it is far easier to make a mirror than a lens. You see the mirror has only one surface to be made; you must be careful to get that surface as nearly perfect as possible, but when that is done your work is over. But a lens has at least four surfaces; for to get rid of colour we must put two lenses together, balancing their colour effects, but leaving the focussing effects unbalanced. Each one of these four surfaces must be as carefully made as the single surface of the mirror; and besides, we have to be very careful that the glass inside is as perfect as possible, since a slight flaw in it will make trouble and confusion at the focus of the telescope. You may ask why, then, do astronomers bother to make lenses at all, since mirrors are so much easier? Well, there are several reasons, but I will mention only one: a lens can be made to show more of the sky at once. When we look through a mirror-telescope (or, let us say, when we photograph with it, for that makes the explanation simpler), then we see that the objects in the middle of the picture are in good focus, but not those at the edges. Perhaps many of you have got cameras of your own, kodaks or brownies, or some other sort, and you may know the difference between good and bad lenses—with a good lens all the picture is in focus, with a poor one the edges show up fuzzy. Well, with a mirror we cannot help the edges being fuzzy, because we have nothing we can alter. If we try to alter the

surface, we shall put the centre of the picture out of focus, which leaves us no better off than before. But with a lens we have four surfaces to deal with and can set one against another, much in the same



Photograph showing very bad edges, though good in centre.

way that has been already done for colour; a little alteration in one can be accompanied by such a corresponding alteration in another that the edges of the field are improved while the centre is no worse off. This way of setting one thing against another becomes even more easy when we have three or four

lenses instead of two only; we can then arrange to get quite a large picture with no fuzziness anywhere.

Let me now tell you a little about some of the largest lenses in the world. They have nearly all been made by an American firm called Alvan Clark. It would have been nicer for us to say that they were made in England: we have, however, the satisfaction of knowing that an Englishman, the Rev. W. R. Dawes, was chiefly instrumental in drawing attention to the excellent workmanship of the Clarks: so that when a big telescope was to be made, the order was placed with them. One of their first successes was a 26-inch lens built for the Washington Observatory; and almost directly it was pointed to the heavens, two tiny moons of the planet Mars were discovered with it. Up to that time Mars was believed to have no satellite: When in 1832 Tennyson was writing the "Palace of Art," he put in some astronomical verses, including the line—

"She saw the snowy poles of moonless Mars,"

but these verses were left out of the poem, and not published until 1898, when two moons had been discovered, so that the line was altered to

"She saw the snowy poles and moons of Mars."

Another interesting thing about these moons is that Dean Swift jokingly predicted them in his *Gulliver's Travels*. He speaks of the astronomers of Laputa as having

"discovered 2 lesser stars or satellites which revolve about Mars."

Of course he was only writing in fun, but an old proverb says that "There's many a true word spoken in jest," and so it proved in this instance.

Soon after this the Czar of all the Russias wished to have the largest lens in the world for his observatory at Pulkovo, near Petrograd. The Alvan Clarks were given the order for a 30-inch lens, and at the same time the machinery for the telescope was to be made by the brothers Repsold at Hamburg. As a young man beginning astronomy, I had the privilege of seeing this great telescope in the workshop at Hamburg in 1884, and I well remember my astonishment, not only at the size of the telescope, but at the number of beautiful devices for working it, especially at the eye end. When an astronomer is looking through a telescope, it is a great convenience to him to be able to make notes and measures of what he sees without taking his eye away: William Herschel had his sister Caroline to make the notes for him, but other astronomers have not had such devoted sisters. The Repsolds had accordingly arranged for the observer to do all manner of things by pressing this button or turning that screw, while he was still looking continuously at the star or planet under observation. But no arrangements are perfect, and an eminent German astronomer who was inspecting the telescope when I was there pointed out that this complicated apparatus would infallibly collect much cigar ash!

The Czar was not allowed to remain long in possession of the largest lens: one of 36 inches was ordered for the Lick Observatory and again the Alvan Clarks succeeded in making it. James Lick

was a rather eccentric millionaire in San Francisco, who would probably have spent his money in a very different way but for the persuasiveness of an astronomer, Mr. George Davidson. There are many stories about James Lick: perhaps you would like to hear one of them. A great many people applied to him for work, and he had a curious way of deciding whether to give them employment or not. He attached great importance to their obeying orders, however stupid the orders might seem. So when a man came asking for work, he would set him to plant trees upside down, with their roots in the air and their branches in the ground! Those who set to work without protest he kept in his service; but if a man objected or asked questions, he was sent away. You can well imagine that a man like this had queer ideas about what to do with his money, and he was chiefly anxious to have some great memorial to himself. Mr. Davidson persuaded him that a large telescope would be a very good form of memorial; and the bones of James Lick now rest under the great 36-inch telescope on the top of Mount Hamilton. He died, indeed, before it was completed, and was temporarily buried elsewhere: but when the great telescope was at last in place, his bones were dug up and deposited under his chosen memorial. Only one possibility seems to threaten their peaceful rest: California is rather a region for earthquakes, and already the Observatory has been twice seriously shaken. San Francisco was, as you know, wrecked by an earthquake some few years ago. The Lick Observatory is some distance away from

San Francisco and only suffered slightly, but a telescope is a delicate instrument that cannot stand much shaking without being damaged. We must hope that good luck will attend the future.

One achievement of the Lick telescope was to discover a new satellite of Jupiter in 1892. Of course the telescope could not have done it without the sharp eyes of Professor Barnard behind it; but we must give the telescope its share of credit, for very few others have managed to show the satellite even now we know it is there, and it is much easier to see something after it has been discovered than to find it in the first place.

It was a condition attached by Mr. James Lick to his gift that the public shall be allowed to use the telescope one night a week, and a great number of visitors go up the mountain on Saturday night just to get a few minutes looking through this great instrument. I am afraid many of them are disappointed, for they expect to see all that they have read about in books or seen pictures of. Now what is set down in books is often the outcome of very careful watching by skilled observers: it cannot be seen every moment, but only on favourable occasions: and without a "seeing eye" it cannot be seen at all. But some of the visitors perhaps only want to say they have looked through the telescope, without caring much what they see.

The largest lens in the world at present is that at the Yerkes Observatory near Chicago. Perhaps you would not call it *very* near, for it is about 70 miles away; but it was a millionaire of Chicago, Mr. Yerkes, who gave the money for it and wished

Chicago to have the credit of the largest telescope, so we must regard it as belonging to Chicago. The Observatory is on the shores of a lake which is now called Lake Geneva, but which had a more beautiful Indian name, Kish-wau-ke-toc, meaning Big Foot, from its shape. The lake is a kind of summer resort for the rich people of Chicago, and when the train comes in, you can see crowds of steam yachts waiting to carry them to their various houses round the shores of the lake, just as we might see a number of motor-cars at a big terminus in England.

The great Yerkes telescope is 60 feet long and has all sorts of beautiful and powerful mechanism to work it. The floor on which the observer stands can be raised or lowered, so as to give him a comfortable position for any object he wants to look at; and this is worked electrically; so that pulling a lever is sufficient to start the mechanism. Pulling another lever starts a motor which turns the great dome round: and generally, by pulling one lever or another all the things can be done which in smaller observatories are done by hand. To get enough electric power for all these things there is a "power-house" placed at some little distance from the telescope. One curious visitor enquired if they put it at that distance because they were afraid it might explode and damage the 100,000 dollar telescope; but the astronomer said no, that was not the reason; they did not fear an explosion, as might be seen from the fact that the power-house was close to his own dwelling-house in which there was a million-dollar baby!

You probably want to know how much these huge telescopes will magnify, and you may be surprised at my answer, "As much as ever you like;" but that is the actual fact. Any telescope can be

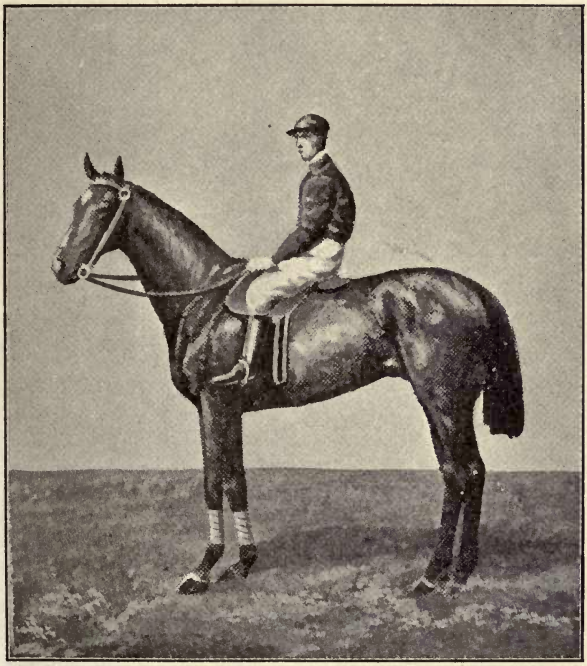


Fig. 29.

made to magnify a thousand times, say, but it does not follow that you will be pleased with the result. The magnifying depends partly on the big lens or mirror about which we have been talking and partly on the "eyepiece," the little lens you put your eye

to. If the object is not magnified enough you can take out this little eyepiece and put in another which magnifies more. Perhaps you have had your photograph taken and " enlarged " : something of the same kind happens with a telescope, the big lens or mirror makes a little image and the eyepiece enlarges it. Now you may have noticed that when

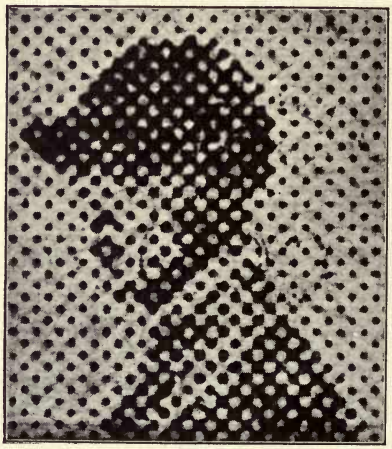


Fig. 30.

your photograph is enlarged, various defects appear which were not noticeable in the original small photograph : and the more you enlarge it the more these defects are emphasized, so that to enlarge it beyond a certain point is no advantage. Fig. 29 is a picture of a horse and jockey from the *Daily Graphic :* and an enlargement of the head of the jockey. The enlargement (Fig. 30) shows that the head is all composed of little dots, and though these

do not trouble us on the small scale, they become obtrusive in the enlargement. In the same way if you try to enlarge the image made in a telescope beyond a certain point the defects become glaring and you get no advantage. These defects are due partly to fault in the making of the lens or mirror (because no workmanship can be quite perfect) and partly to the tremulousness of our atmosphere. All kinds of cross currents are continually passing in the air through which we are compelled to look at the heavens; and they all tend to blur and confuse the image. When we do not magnify it much we do not see these blurs; but a high magnification makes them obvious.

This illustration of the jockey reminds us of another fact about a large telescope: we cannot see much at once. In the original picture we see not only the jockey but the horse as well, but when we enlarge it, we must be content with the jockey's head if we are to have the patch of the same size. Perhaps you will ask why we need have this limited patch at all? Why not make the whole picture bigger? I am trying to show you what you actually see when you look through a big telescope: and you will always find your vision bounded by a ring, which limits the "field of view" as it is called. In using a telescope you have to put your eye to a small hole in the eyepiece. Fig. 31 is a picture of the great nebula in Andromeda, and the little hole in the covering screen enables us to see just about as much of it as we should see at one time in a large telescope. If we move the telescope about, we can change

the bit we look at. If you cut the screen loose, you can move the hole about over the picture and get an idea of the whole in that way. It is a tedious process, but it was the only way astronomers

Fig. 31.—The Great Nebula in Andromeda.
(See Notes to Illustrations.)

had of examining a large object like this when they used their eyes and had not learnt to take photographs: and you cannot wonder that they got imperfect ideas of them. The eminent astronomer Trouvelot drew a picture of this same nebula,

before the days of photography : and he made those dark rifts practically straight lines, which misses the whole point of the structure.

When, however, we take a *photograph*, the eye-piece is taken away and the light shines all over the plate at once, so that we are no longer confined to a small ring, but can photograph the whole object at once, faithfully : we see that these rifts are not straight but delicately curved, in a way suggesting that there are several rings whirling round the central bright nucleus. This has a very important bearing on our ideas of the formation of stars from nebulæ : but the drawing made by Trouvelot was meaningless.

Let us take another point about a large telescope. We have chosen a telescope as our travelling car, and we must learn all about it, not only how it is used, but how it set up. You can well imagine that it is rather a business to construct a telescope like Lord Rosse's, big enough for a man to stand up in. Fig. 32 shows one in which a man is not standing up, but lying down, to do some part of the fixing. This is the great Victoria telescope which Dr. McClean presented to the Royal Observatory at the Cape of Good Hope in honour of good Queen Victoria, whom many of you may not remember. We must hope that some one will give a big telescope in honour of King George V, mustn't we?

Now not only is such a telescope awkward to set up, but it is rather awkward to work after it has been set up, unless special arrangements are made. One modern comfort is the rising and falling floor which I mentioned in connection with

the Yerkes Observatory. It was designed originally by Sir Howard Grubb, for use with the great Lick telescope; and has been generally adopted for all large telescopes of that pattern. Presently we will notice a different method of working a large

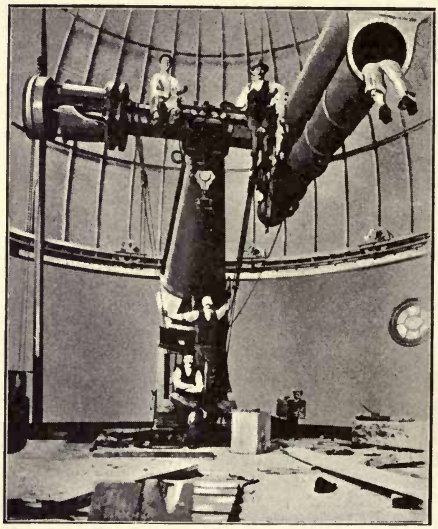


FIG. 32.—The Victoria Telescope at the Cape of Good Hope.

telescope, but before doing so I want to remind you that since our Earth is steadily turning round on its axis, a telescope would soon lose a star unless there is clockwork to counteract the Earth's motion. You know how the various constellations change during the year: there is a little rhyme, made by the good Dr. Watts, which enables us to remember some of them, perhaps you know it already—

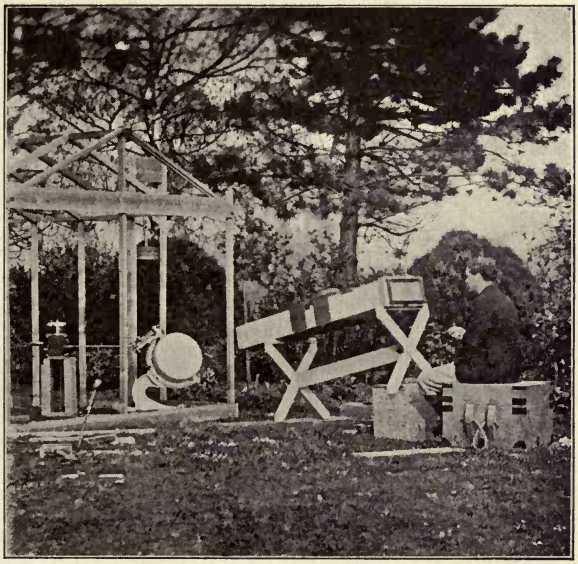
The Ram, the Bull, the Heavenly Twins,
And next the Crab, the Lion shines,
The Virgin and the Scales.
The Scorpion, Archer, and Sea-Goat,
The Man that bears the Watering-Pot,
The Fish with shining tails.

That is the order in which the constellations in the Zodiac are arranged, and the Sun appears to visit them all in turn once a year, owing really to the fact that the Earth travels round the Sun. But the Earth also rotates on its axis, as we learnt in the first lecture: and in consequence of this rotation all these constellations cross the sky every day. Some of them cannot be seen to do so, because they are too near the Sun: they cross in the daytime when we cannot see them; but the others cross at night, and if you care to notice at this time of year (early January) you can see the Twins rise in the east soon after sunset and cross the sky much in the same way that the Sun does, setting in the west long after you have gone to bed. If, then, we had a fixed telescope it could only catch sight of the Twins once during the night; but if we arrange that it can turn round by clockwork it can keep the constellation, or any part of it, steadily in view, all night if necessary. Sometimes an astronomer wishes to look steadily at the same object all night in this way: he would probably be also taking a photograph at the same time, of some very faint light such as a faint distant nebula, which would not appear on the plate unless he gave it a very long exposure. So he points the telescope at the object, sets his clockwork going, puts a photographic plate to receive the image: and then in another

telescope (firmly attached to the photographic one and moved round by the same clockwork), he watches to see that the clockwork is going smoothly and accurately. If it is not, he has the means of correcting it by pressing an electric button. But it is very tiring to watch for long hours like this, and he is generally glad when the first signs of coming daylight warn him to put the cap on his telescope. Sometimes even then he knows that he has not given a long enough exposure; the object may be so faint that even a long winter night of twelve hours is not long enough for it. What is he to do then? Why! he must cover up his telescope most carefully so that no light can get to the plate during the day: and when darkness comes again, he must turn the telescope to the east where the object will rise, set his clockwork going again, take off the cap, and spend another night watching to see that all goes well. Perhaps even two nights are insufficient, so that he must add a third and a fourth: and I need scarcely remind you that all nights are not fine; when there comes a wet or cloudy night, the astronomer must keep his telescope covered up and wait until the weather improves. So that sometimes a plate has been kept in the telescope for many months before the full exposure has been given. You may not have realized what long hours of waiting some of the beautiful pictures of the heavens which you can now see so easily may have cost!

Now we can return to the way of working a big telescope. One of the most recent modern improvements is to attach the clockwork, not to the telescope itself, but to a mirror which reflects the

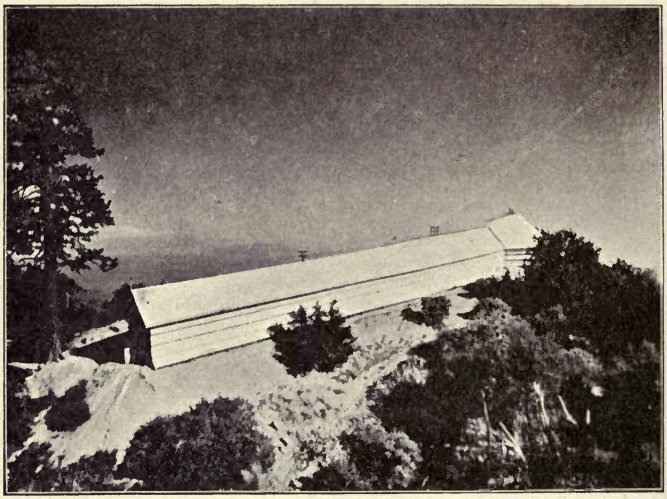
light into it. The mirror is in this case a flat mirror, not concave so as to bring the light to focus, but made perfectly flat so that it simply turns the light in another direction without altering it. All the alteration is to be done by the telescope, which can



A Coelostat being prepared at Oxford for the Eclipse Expedition of 1896.

now be firmly fixed: the mirror is turned about by the clockwork so as to send the light always into the fixed telescope. A mirror so arranged is called a Coelostat, which means "sky standing still": and it is an actual fact that if you look into such a mirror at any part of the sky, it will no longer appear to move as the real sky does, but remain steady

and constant. You may ask whether we can prevent a constellation setting in this way: of course we cannot do that: a constellation will seem to remain steady as long as you can look at it: but the mirror is being turned round by clockwork, and in course of time you will find that it will present



The long shed for the Snow Horizontal Telescope on Mount Wilson, California.

its edge to you, and then its back! so that you can no longer see the constellation, which takes the opportunity to set below the horizon.

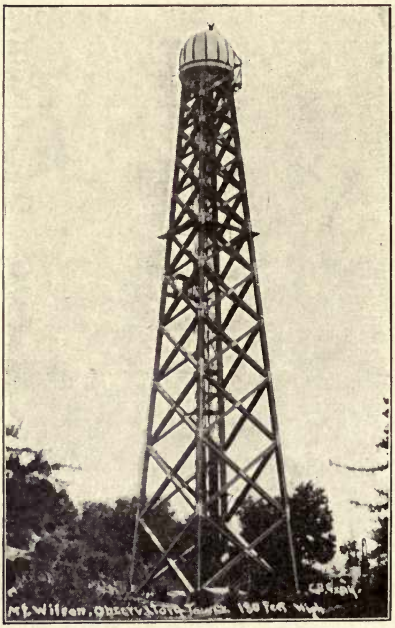
When a coelostat mirror is used in this way we can fix the telescope in any position we like within certain limits. One position which very naturally occurs to us is the horizontal one. If we lay the big telescope on the ground, there is no danger of

its falling: and it is in other respects convenient to work with. Hence several large telescopes have already been built in this way. A good example is the Snow telescope on Mount Wilson. You see in the picture the long shed which is really the telescope itself: and at one end there is the coelostat mirror, reflecting the light (in this case usually the light of the Sun, not that of a star) into the telescope.

But there is one great disadvantage about this horizontal position. The ground gets heated during the day and causes air currents to ascend from it. Now currents of heated air blur the image (see p. 143) and are to be avoided as much as possible, whereas the horizontal position of the telescope seems to encourage them. Hence, Professor Hale tried the plan of putting the telescope vertical instead of horizontal. He built, in the first instance, a tower 60 feet high. The coelostat mirror[1] was placed on the top and the rays from the Sun or stars sent down to the foot of the tower, where they could be examined or photographed. This new move was found to be so successful that a more ambitious experiment was tried. A tower 150 feet high has been built to carry the coelostat at the top: by it the rays of the Sun are reflected down to the ground but do not stop even there, because a well 80 feet deep has been dug below the tower to receive them, so that the whole length of travel

[1] There are really two plane mirrors, one moved by clockwork as already described, the other fixed. If we had only the first mirror, then any part of the sky would indeed remain stationary, but the telescope must be pointed to it in a particular direction. The second mirror makes it unnecessary to point the telescope.

is 230 feet. We have got back to the length of those long thin telescopes which were found so inconvenient two hundred years ago; but now they are no longer inconvenient because they need not be moved about, but can be fixed upright



The High "Tower" Telescope on Mount Wilson.

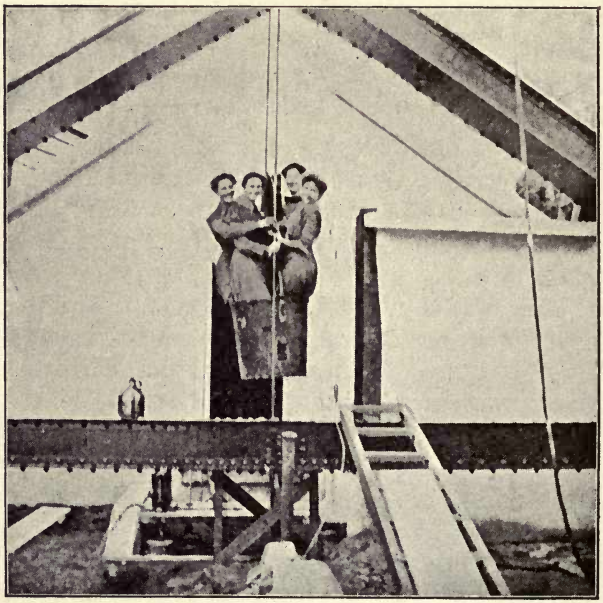
once for all. That is of course not altogether an easy matter, because a telescope must be fixed very steadily; it will not do, for instance, for it to be shaken by the wind. How are we to prevent a tower 150 feet high from being shaken by the wind? Professor Hale thought of a trick as neat and simple

as a conjuring trick—one of those dodges that is so easy when once you know and so difficult beforehand. If any of you likes to test his own brains let him try to think for himself how this was done: and to give you a little time to think I will not tell you the answer just yet.[1] We will look at this picture (p. 124) of the ladies who do the calculations at the Mount Wilson Observatory, ready to ascend the 150-foot tower in the bucket which acts as a lift, and then we will leave the tower for a time and go down into the well, where all kinds of apparatus are available which it would take us several courses of lectures to explain fully, but of which we may get some idea without working too hard.

Let us first think of the three essential parts of a telescope—any telescope—we might take the very first that Galileo looked through. There were two lenses joined by a tube. Now these three separate parts of a telescope have each had histories of their own which we have partly reviewed already. The tube went ahead first; you remember how the tube became immensely long, because of colour, without any great alteration in the lenses: then one of the lenses (the *object-glass* as it is called, because it is turned to the object: the other is called the *eye-lens* or *eyepiece*) became a mirror and was made much larger, while the tube shrank back to normal size. We thereupon followed the history of the mirror, seeing how it became larger and larger:

[1] The answer is given at the end of the chapter, but I would urge all and sundry to try to guess it for themselves, if they do not happen to have heard it.

and how, when the difficulty of colour was got over, large lenses also began to be made. Meantime the tube had to grow to keep pace with the growth of the object end, and the old difficulties of unwieldiness had to be faced afresh; and so we came back



The Computing Staff about to make their first ascent of the "Tower" Telescope in 1910.

to the tube and learnt about the coelostat, and ultimately about Professor Hale's great 150-foot tower. But all this time nothing had been said of the poor eye end, which seems to have been left quite out in the cold: and indeed its history did not begin until later, but once begun, it has been far

the most eventful of the three, because there has been much more variety in it. The object end and the tube have changed chiefly in size; but the eye end had become a photographic plate, or a spectroscope, or a photometer, or a spectroheliograph, or any one of a number of such things which can be attached at the eye end. One of the practical problems of an astronomer is to change one of these pieces of apparatus for another as easily and rapidly as possible: and Professor Hale has devised the best method up to the present. Perhaps some of you have on your breakfast-tables a dumb-waiter which can be turned round, so that you can get at the butter or the toast or the marmalade when you want it? There is a contrivance of a similar kind down in the 80-foot well below the 150-foot tower. Of course it is much bigger and stronger than your breakfast-table apparatus: but in just the same way, and almost as easily, as you help yourself to toast first and then jam, Professor Hale can put on the spectroheliograph first and then the polarimeter, say, or whatever he wants to use.

Up to the present, the only one of these things that we have said much about is the photographic plate. We can take away the eyepiece of a telescope (and also the eye that looks through it) and substitute a photographic plate, and some of the advantages of doing this have already been mentioned, especially that the plate can look at much more of the sky at one time. We also mentioned that the plate could be exposed for many hours, and in this it has another advantage over the eye, because it is steadily photographing more and more (that is,

fainter and fainter objects) all the time, whereas the eye gains nothing by continuing to gaze—it rather loses by getting tired. Another advantage is that when the plate has been developed, it can be copied and the copies sent all over the world: or it can be preserved for many years: or it may be measured at leisure; and so on. The catalogue of advantages is quite considerable, so that the introduction of photography into astronomy has effected nothing less than a revolution.

But scarcely less of a revolution has been effected by the spectroscope, which tells us what the stars are made of, by means of that very colour which was at first simply a nuisance. A great man once said that it was quite certain that we should never know what the stars were made of: but it is now quite certain that we do. You remember the experiment with the prism which showed us the different colours of the rainbow? I now want to show you that these colours are not always the same. We will first throw them on the screen with ordinary light, when they have the familiar appearance; but now we will put a salt of sodium in the source of light and immediately you see that the yellow becomes very bright—much brighter than the rest. (See spectrum No. 4, plate facing p. 273). That effect can be produced by common table salt, which is a salt of sodium; and we know when there is some sodium in the light by this brightening in the yellow. But we can improve the apparatus until we find that the brightening is very local—sodium does not brighten all the yellow, but only a particular part or line of it. If we improve the apparatus still

The Cities of Pasadena and Los Angeles as seen at night from the Mount Wilson Observatory.

further the line splits up into two : and with further and further progress these lines are so clearly separated that hundreds of other lines can be seen between them. We might spend a lifetime examining these lines : but at present I want us to be content with the very simplest facts which will give us a general idea of the spectroscope.

Now let us try another experiment. We will again put in some sodium and you see the bright line in the yellow : but soon you see it changes to a dark line—instead of the yellow being brighter than the other colours, it is much darker. (Look at spectrum No. 10, " Sirius," plate facing p. 273) The reason is that the sodium has now been put in in such a way that it gives off clouds of its own vapour, and these clouds stop the yellow light though they do not stop other light. The discovery of that fact is one of the greatest discoveries ever made, for it enabled us to read the heavens like a book. Until it was made nobody could understand the meaning of the dark lines which cross the spectrum of the Sun : they were thought at one time to be boundary marks of the different colours. Now we know that they vouch for the presence of sodium and other chemical elements in a state of vapour, stopping the light of particular colours and letting other light pass on. It is as though a French policeman were stationed at the gangway of a steamer, stopping all Frenchmen from disembarking : all other nations might pass—English, Germans, Portuguese, Chinamen, Hottentots and all others—because the French policeman would have no authority over them; but he would stop

every Frenchman, and so there would be none in the miscellaneous crowd issuing from the gangway: and if we could notice this absence of Frenchmen, we might say "Why! there must have been some French officials stopping them at the gangway." So in the same way when we see the absence of a sodium colour (or an iron colour), from the light of the Sun, we say, "There must have been some sodium vapour (or some iron vapour) stopping the sodium light (or iron light) at the gangway (that is, just where the light was leaving the Sun)."

It may seem strange that we notice the light which is stopped rather than that which comes to us. Why should we not rather look for a *bright* light sent out by sodium, like that I showed you first? Well! we often do: but the dark lines, shown in the second experiment, are much commoner, and have told us on the whole far more than the bright lines. The fact is that the stars are mostly very very hot, so that there are masses of vapour surrounding them through which the light must pass. The stoppages are therefore far the most conspicuous features of their light.

You will understand from this brief description what a spectroscope is. The chief part of it is the prism[1] which spreads out the light into a band of colour: but we must be careful to limit the light to a narrow line or "slit," otherwise we shall not see the stoppages distinctly. We can either examine the result with the eye, or we can photograph it:

[1] Instead of a prism we can use what is called a "grating"; but the general result is the same.

and there are much the same advantages in photographing here as in the case of the direct light.

But we can also do something else. When the light is spread out in this way we can throw most of it away and keep only one colour, and then nothing will shine unless it has that colour. Let us do another experiment or two with our prism. Here is the light spread out into colours as usual, and now I will take a red ribbon and put it in the red light: you see it looks red as usual, but in the green or blue it looks black—it gives us no light. Here is a yellow ribbon which shines yellow in the yellow light, but when I put it in the red or blue it looks black: and so on.

We will try another experiment. Instead of spreading out our light into colours, let us take light of only one colour, to begin with. We can do that by putting some common table salt into the flame of a spirit-lamp, when it will blaze with that brilliant yellow colour which we have seen is due to sodium. Now here is our bunch of ribbons of all colours, which perhaps one of my audience will kindly hold: when we burn our table salt only the yellow ribbon will show—the others will all appear black—but we are not quite ready yet. Here are some letters of different colours pasted on this board, which perhaps two others of the audience will hold: and here again is a picture in colours for some one else. You see all these coloured objects in ordinary light: now we will darken the room and put in the table salt, and in the weird yellow light you see only the yellows—all the other colours appear black, but we see at a glance where there is any yellow.

On this principle is constructed one of the instruments that replace the eye end of the telescope. It has a terribly long name—the spectro-heliograph: spectro from the colours, helio from the Sun, which is usually the picture experimented upon; graph because the records are written by photography. The thing it does is to make a picture of the Sun in one colour, just as we used only yellow light to look at this picture. Then all the parts which have any yellow (or red or whatever colour we choose) show up, while the rest remain black. We can tell at a glance whereabouts there is any sodium (or hydrogen or whatever gives that colour) in the Sun. Suppose we could apply this process to the Earth and take a picture of it showing just where any gold was, would that be a good plan, do you think? London would be a bright spot, and New York and other big cities; places like Alaska would show up, if the gold is not yet all dug out; and then there would be other spots which nobody knows of yet, where the gold is still in the ground,—what a rush there would be to them! The pictures of the Sun do not show us the distribution of anything so exciting as gold, but what they show us is nevertheless of great interest to astronomers, and we will say more of it when we visit the Sun.

I will tell you about just one more of the things we can put on the end of a telescope—something rather simpler this time because perhaps you may think we are getting too complicated for comfort. The point of this instrument is merely its great sensitiveness—it detects variations in light which the eye cannot notice. There is a star called Algol

which we may translate " The Wonderful " (" Al " is the Arabic for " the," and " gol " is the word used for genii or fairies in the Arabian Nights, for instance : though it is mixed up with the word " ghoul," which

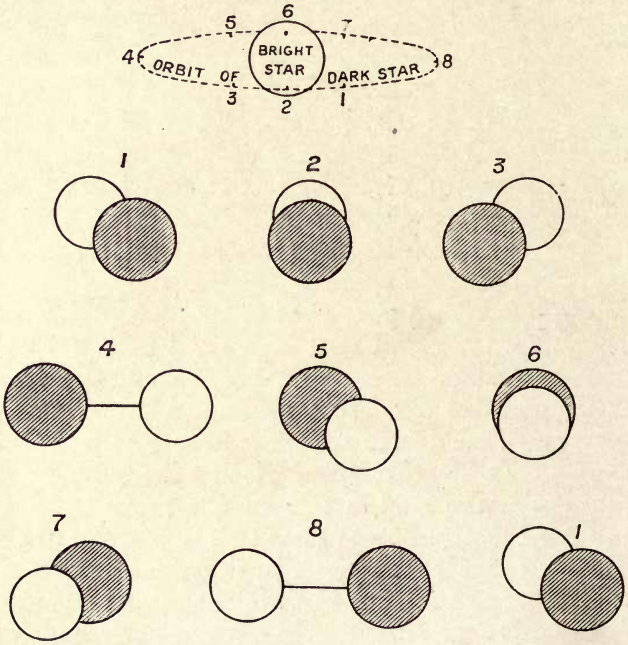


Fig. 33.

is not so pleasant in association). This star behaves like the light of some lighthouses, it shines steadily for a time and then goes faint. The steady shining lasts for about three days and then comes the dip. Now the eye is able to see this without any telescope at all; and we can interpret the dip to mean that something comes in front of the light. Imagine two

bodies, one of them bright, the other dark, revolving round each other (Fig. 33). So long as the dark body is clear of the bright one, or behind it, the bright one shines steadily: but if the dark one gets in front we have an "eclipse" and the light dips. This imagination or suspicion has been confirmed

Punch's Representation of Algol, "An Astronomical Reprobate."
(See Notes to Illustrations.)

in a remarkable way by the spectroscope; and from being only a hypothesis has become a serious addition to our knowledge—so serious that it has been honoured with an illustration in *Punch* by that clever artist Mr. E. T. Reed. By kind permission of the proprietors I am able to show you the picture.

But what I now want to tell you about is the new

knowledge we got simply by watching more carefully with a new kind of photometer invented by Mr. Joel Stebbins in America. The principle of it can easily be illustrated by an experiment. There is a substance called selenium, which is sensitive to light, so that when light falls upon it the resistance alters, and that spot of light on the screen will move. The selenium is shut up in this box, so that light shall not disturb it, otherwise the spot would be moving about instead of remaining steady. But now we will darken the room and open the box: so long as the box remains still in the dark the spot remains steady; but now we shine a taper on the selenium and you see the spot move off at once. You will understand that by using this principle, Mr. Stebbins was able to tell when a star was shining on his selenium and also how bright the star was: and though he had many difficulties at first, he got over them so successfully that in the end the instrument could tell the brightness of the star much better than the human eye could. I will mention just one of his difficulties. He found that the instrument behaved differently in warm weather and cold, so that to get consistent results he determined to keep it always at the freezing temperature by packing it in ice. In America there is always plenty of ice to be got, but it is generally used for cooling drinks: and when Mr. Stebbins sent in his bill for all the ice wanted to keep his photometer cool, the authorities pretended to think that he must have required a great many drinks. But Mr. Stebbins was so determined to make his photometer work that he bore even practical jokes in the good

cause. And now I want to show you what beautiful results he obtained. We may represent what the eye saw by the diagram of Fig. 34. The time when the light is steady is represented by the horizontal lines like CD and FG: the eclipses by the sudden drops ABC and DEF. But the first thing found by the selenium photometer was that in the middle of the straight portions (or what had been thought to be straight portions) there was another little drop—so small that the eye had overlooked it. What does this mean? The big drop ABC means that the dark body comes in front of the bright one: the little drop means that the bright one comes in front of the dark. If it were *entirely* dark, that would of course make no difference: and since there *is* a noticeable difference, it follows that the second body cannot be entirely dark, but must be giving off some light which is cut off when the brighter body comes in front. This, then, was the first thing found out; but there is more to come. Not only is there a little dip in the middle of each supposed straight portion, but the remaining parts of those portions were found to slope slightly in opposite directions, as shown in Fig. 35. This means that even when the two bodies are clear of one another, and no eclipse is taking place, the light is still changing in some way. Mr. Stebbins was able to give the

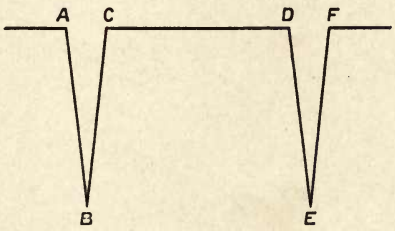


Fig. 34.

explanation very easily. He pointed out that the bright body must be shining on the dark one, just as the Sun shines on our Earth and our Moon : it will illuminate half of it, and this half will be turned sometimes towards us and sometimes away from us, just as the Moon is sometimes full and sometimes new. This is seen easily enough in the case of the Moon, but in Algol we cannot see the two bodies separate from one another, we only see their combined light; nevertheless by these delicate observations we can say when one of them is full and when it is new just as easily as we can put the times of full Moon on the almanac. Is that not a wonderful result of patient work? And there is still more wonder to come. Mr. Stebbins found that he was able to calculate how large these two bodies were and how far apart (Fig. 36), and he found that the bright one must be 240 times as bright as our Sun, and even the fainter one, which has hitherto been called " dark," is 16 times as bright as our Sun ! I think you will agree with me that this is a wonderful addition to our knowledge; we have been able to find out that a star which always appears just as a speck of light is really made up of two at a certain distance apart, one very bright and the other faint, partly shining of itself and partly being illuminated by the other : and that

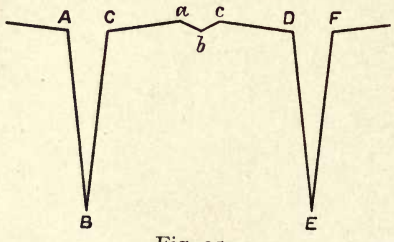


Fig. 35.

even the dark side of the fainter body is 16 times as bright as our Sun. And the chief part of this knowledge comes, not from using a very large telescope, but from putting a sensitive apparatus in place of the eye end.

There is one more thing I must tell you in concluding this lecture. I must answer the question about Professor Hale's tower—how it is kept from shaking. We could keep a reed from being shaken by the wind if we enclosed it in a tube: the wind would blow on the tube and perhaps shake it, but

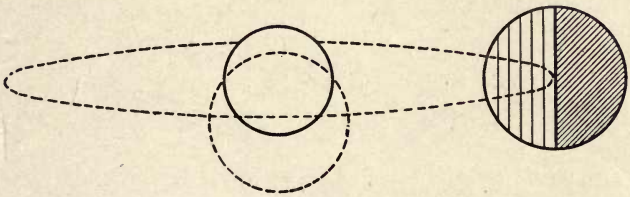
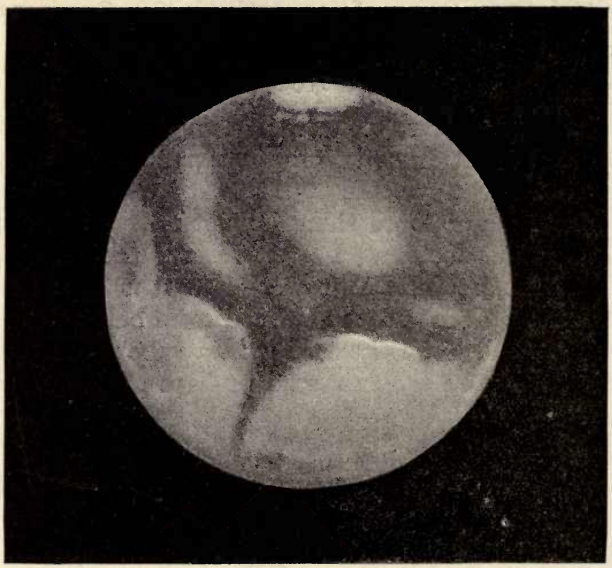


Fig. 36.—Mr. Stebbins's Representation of Algol.

could not get at the reed. Professor Hale's idea is to build a tower of rods and surround each rod by a tube, joining all the tubes together to form an outer tower or casing, on which the wind may blow and which perhaps may shake, but which keeps the wind off the inner tower altogether. The coelostat is of course attached to the inner tower, so that it may not be shaken. "The proof of the pudding is in the eating," and such an idea can only be justified by trying it. It has been tried and found completely successful. Professor Hale finds that even in high winds the image of the Sun in his big tower telescope does not shake at all!



The Planet Mars, as drawn by N. E. Green.
(See Notes to Illustrations)

LECTURE IV

VISITS TO THE MOON AND PLANETS

You may perhaps think that we take a long time getting started, seeing that we have spent three lectures out of six in discussing where we are to start from, in what we are to travel, how far we are to go, and so on. But I find that this is the method approved by my great predecessors as celestial guides. Jules Verne, you find, takes a whole book talking about the start; how the big gun is to be built capable of shooting people to the Moon; how, moreover, a big telescope is provided to watch them when

they go; and it is only at the end of the first book that they really get started.

However, here we are now started; and if we are not exactly arrived on Mars, we are as near Mars as the telescope will take us; let us say about a thousand times nearer than our eyes can take us. I told you that the telescope would magnify as much as you like, but that you might not be satisfied with the result if you magnified too much. Roughly speaking, the best telescopes we have will magnify about a thousand times, so that we reduce the distance of Mars to about one thousandth of the actual distance, let us say 50,000 or 100,000 miles; and that is as near as the telescope will take us. One peculiarity of a telescope is that it usually turns things upside down, so that the South appears at the top. The white patch at the top of the picture is therefore not the North polar cap but the South polar cap. I wonder whether any one is at present making a South Polar Expedition in Mars? It is claimed that the white patch represents ice and snow, such as we have at the poles of our Earth; others, however, question whether it can be ice and snow, because certain observations made with the spectroscope render it a little doubtful whether there is sufficient water in the air of Mars to make ice and snow at the Poles. One thing we know with certainty; that in the Martian Summer the cap diminishes in size as though it were ice and snow melting, and in the Winter it increases in size as though it were ice and snow forming. But, after all, other things besides water may give this appearance. At the end of the lecture, when we come to an experiment or two, we shall see

that liquid air may give a beautiful snowy appearance, and it is possible that the Martian polar caps are not made of ice and snow but of liquid air or frozen carbonic acid gas, or some other gas which on the very cold surface of Mars becomes liquid or even solid.

There are other markings on the picture, but what you will probably look for are the famous canals of Mars. I am afraid there are none shown on this picture because Mr. N. E. Green, who made it, did not see any canals. Some people do not see them, and claim that therefore they cannot be there. One scarcely knows what to say about this claim : it is rather like calling witnesses, after others have testified that they saw a theft committed, to declare that they did not see the theft. We should probably pay more attention to the first lot who saw something and agreed among themselves about it. Nevertheless, we must be careful to listen to the others also, in case there is more in what they say than might appear at first. A jury must be very careful before they find a man guilty, and one thing they must be specially careful about is not to let their feelings of affection or dislike influence them. So well known is it that such feelings may interfere with true justice that every effort is made to have the jury composed of people who do not know the prisoner being tried, because a friend might interfere with justice in one way or an enemy in the other. Now in this case of the canals of Mars it is rather harder than usual to keep the friends and enemies off the jury. Some people are very anxious to believe that the planets are inhabited and they are inclined to jump at any-

thing which seems like an indication of life on Mars. Others are equally anxious that our little Earth should be the only place in the whole universe with life upon it; does not this seem rather selfish? Yet a very great and unselfish man, who helped to make one of the greatest of scientific discoveries, has written a big book to try and establish this fact—that this little Earth of ours is the only place in the whole universe on which there is life. All the thousands of millions of stars in the sky may be suns like ours, and each of them may have many planets circling round it as we circle round the Sun, and yet Mr. Alfred Russel Wallace sincerely believes that there is not a sign of life on any of those thousands of millions!

You see there are very different views about Mars and whether it is inhabited; and if we wish to be a good jury we must listen to both sides carefully. But we have not time to do so in this brief hour; all we can do is to notice that there is evidence on both sides, so that we may be careful not to make up our minds too quickly. If you wish to make up your mind at all you ought to read a good many books but it is easier not to make up one's mind at all, and sometimes that is the best plan. Another plan is to get some one to make up your mind for you, and perhaps you hope that I will do it by telling you what I think. I don't feel sure that that would be a good plan in any case, but one thing makes it impossible to act upon, I have not made up my mind myself. At least I have not made it up about Mars. On the big question raised by Mr. Wallace, whether our little Earth is the only place for life, I have made it up;

I don't think for a moment that it is. I have read his book carefully, but cannot see that he makes out a case for so strange an idea. That there is plenty of life elsewhere seems to me practically certain; but whether Mr. Lowell has really detected signs of it on Mars is more doubtful. Of one thing, however, there is no doubt; he has certainly written some most fascinating books, which will teach you much and tell you a story at the same time; I heartily advise you to read some or all of them. The kind of story he has to tell is this: Mars has become dried up, so that it has no great oceans as we have, making rains which fertilize the ground so that plants may grow; there is very little water indeed on Mars. Every one agrees to that. Mr. Lowell, however, says that there is *some* water, mostly frozen up in the polar caps; when these melt at the edges with the coming of Spring and Summer, the inhabitants draw this water off quickly to the thirsty land in long sluices; vegetation immediately springs up on the banks of these sluices, making a wide belt of verdure. Something of the kind may be seen in Egypt when the Nile floods: the surrounding country, previously brown and bare, becomes covered with crops. An observer in the Moon or in Mars might not see the thin river Nile in the dry season, but after the flood, when the whole width of the country is green, he would scarcely fail to notice it. So with Mars: the "canals" disappear at times; then, Mr. Lowell says, there is little or no water in them and the surrounding country is bare and dry. The polar cap melts a little, the water is drawn into the sluices, the crops spring up on the banks, bordering the narrow sluice

with a margin wide enough for our telescopes on Earth to see, and they show us a " canal." From the straightness and arrangement of the sluices thus indicated Mr. Lowell infers that they were made by intelligent beings in desperate need of water; so that he considers the " canals " a proof of life in Mars.

It may surprise you that, if there is really any chance of there being wide tracts of cultivated land, there should be any difference of opinion on the subject. Why can some people see them and others not? I can easily show you one reason. You see here a clear picture on the screen, but you seldom see a clear picture in a telescope because of air currents. By a little trick the lanternist will imitate some air currents for us; and now the picture instead of being clear and definite is all fuzzy, with the details blurred; then perhaps there comes over it now and then a clear moment, when you glimpse it clearly; but almost at once it blurs again, and you wonder whether perhaps after all you really did get that glimpse or whether it was a mistake. You wait for another clear moment, and get the same glimpse; that reassures you that you did see it; but the best way of removing doubt is for some one else to see the same thing. That is the way in which telescope observations are rendered difficult in a bad climate; and that is why people go up high mountains, in order to see whether they cannot reduce the air currents. Even when, like Mr. Percival Lowell, they build a big telescope in a specially good climate to study Mars, they can only grasp a few details at a time; and two pictures made at the

same time by different people may be very different. Fig. 37 shows two drawings made by Mr. Percival Lowell and his assistant on August 14, showing about what they could see at that time; and you see that although they have tried as faithfully as they could to put down what they saw, Mr. Lowell saw a straight canal nearly due North and South, while his assistant saw it slope to the East. When there is difference of opinion of this kind the only way is to make vast numbers of drawings, throwing away what only one

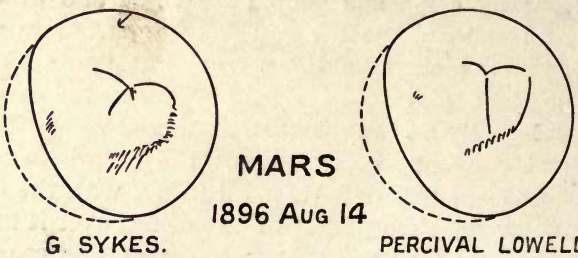


Fig. 37.

man sees, and keeping what everybody sees; in this way only can they really make a trustworthy chart of Mars. You may say: Why not photograph the planet? But photographing is even less satisfactory because the camera cannot always seize good moments as the eye can; it often photographs at the wrong moment. By taking many photographs, however, one after another, we can pick out the good ones; this plan has only recently been introduced, but it has given us already some good photographs of Mars. Fig. 38 shows three taken by Professor Barnard on which you see the polar caps clearly. But, after all, we shall much better understand the

difficulty of coming to conclusions about the planets if now we have got to Mars we take the big telescope that has carried us there and turn it on to

Fig. 38.—Mars Photographed with the 40-in. Lens of the Yerkes Observatory.

the Earth; and let us try what we can see of our Earth from that distance. I propose to arm you with the best telescope in our possession, and to ask

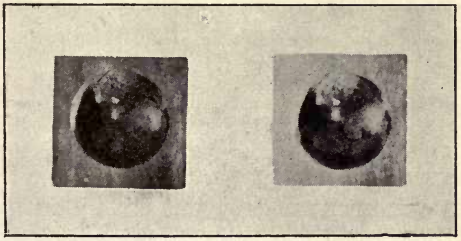


Fig. 39.

you to look with it at the Earth. Of course I must provide you artificially with the view you will get; and Fig. 39 provides two views of our Earth, differing in some respects, but both of them better views than you would have any right to expect if you were really looking from Mars, even with our very best telescope.

You see the outline of Africa and other well-known outlines; these need not be regarded very closely; they are the same in both pictures. The only difference is in the British Isles. To make these two pictures, a globe was photographed twice, in as nearly the same conditions as possible, with one exception: the British Isles were cut out in paper, in the first case in their usual shape, in the second case

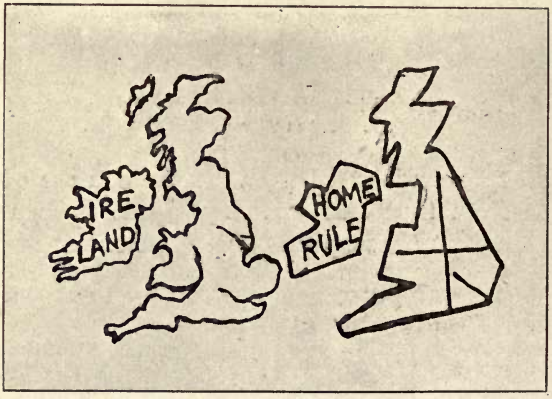


Fig. 40.

in very much altered shape. You will see the alterations in a moment when I put both pictures on the screen; but first I want you to try whether you can see them from Mars. If such alterations were made in England, could the Martians armed with our best telescope detect them at all? Well, you are practically in that position; what do you say? I fancy you cannot detect much difference. Now let us look at Fig. 40 on a scale which will show us their real differences; you see that our well-known wavy

coastline has been made straight, various islands, such as Anglesea and the Hebrides have been swept away, the Thames and Severn have given place to two straight canals, and there is Home Rule in Ireland! Of all this you as Martians could detect nothing, even through the best telescope. How, then, are we to find signs of life in Mars? You will perhaps agree with me that it is a very difficult quest.

With other planets we can see less still, either

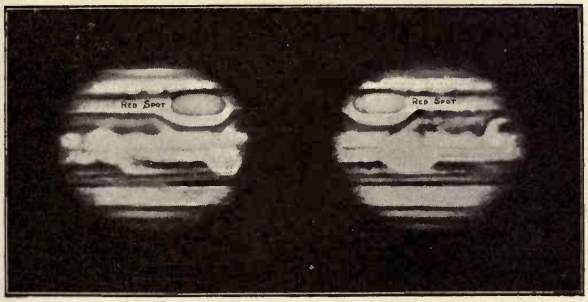


Fig. 41.—Jupiter, drawn by Mr. Scriven Bolton.
(See Notes to Illustrations.)

because they are too near the Sun, like Mercury and Venus, or because they are even further away than Mars, like Jupiter and others. Here are two pictures of Jupiter showing the "red spot" (see Fig. 41). We learn from it that Jupiter rotates on its axis as the Earth does, because the red spot goes round: it crosses the disc, disappears on the other side, and then reappears again. It comes back to the same place pretty regularly after about 10 hours, and other spots on Jupiter, not so large as the red spot but quite noticeable, also return to their places in

about 10 hours; so that this must be about the length of time in which Jupiter rotates. But now comes a curious thing, quite different from what we should expect. If the Martians are looking at the Earth, they see the markings on the surface go round to the other side and then reappear again in *exactly* 24 hours. Everything comes round in precisely the same time, England and Ireland and China and Australia, the mountains, and the seas, all keep their places on the Earth, just as they do on a globe of the Earth which I can turn round. If they did not keep their places we could not learn geography, which would be a terrible distress to us all. But when we look at Jupiter the spots do not keep their places: some of them come round faster than others, so that we cannot make a map which will do for more than a very little time. It is as though the Martians noticed the positions, not of England or China or Australia, but of the ships crossing our oceans. They are scarcely likely to do this unless they have very much more powerful telescopes than ours, because you have seen how very small even a whole country like England would appear to them, and a ship would be far too small. But we keep building ships bigger and bigger, and perhaps the Martians might see them at last; and if they watched carefully they would find that after 24 hours exactly the ship was not quite in the same place on the Earth's surface. Shall we, then, say that the spots we see on Jupiter are ships moving on its oceans? It seems more probable that they are cloud effects of some kind; all we know is that we are not looking at solidly arranged countries like our Earth; and if we want to know what we are

looking at, we have some choice of opinion. Most astronomers would say the spots are cloud effects high above the real surface of Jupiter, which is hidden from view.

Another thing I would like you to realize about Jupiter is his vast size. Here is a model of Jupiter on the scale of 10,000 miles to the inch, and the model is about 9 inches across, so that Jupiter himself must be 90,000 miles from side to side; and now look at our Earth less than an inch across, and our little Moon less than a quarter of an inch. How small they are compared with Jupiter! Why, to go round Jupiter is a longer voyage than from the Earth to the Moon!

Another big planet is Saturn, which I hope you recognize by his ring. In this model we have had to imitate the ring in solid cardboard, but if the real ring were solid like this, it would soon fall on to Saturn, as a great mathematician (Clerk Maxwell) showed by calculation. He went on to show that the ring must be made up of millions of little tiny satellites all separate from one another and revolving round Saturn at different rates. They are, however, so close together that we cannot see them separate even with our best telescopes; consequently we do not see that one travels faster than another, as we can see one of Jupiter's spots catch up and pass another; at any rate we cannot see this in the ordinary way; but by a wonderful property of light, the spectroscope enables us to see it in another way of which we will say more in another lecture. We are able to measure the speed with which a shining body is coming towards us or going away from us;

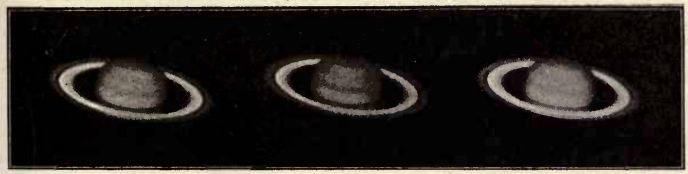
and we find that though we cannot see the satellites separate, their different speeds declare themselves in the spectroscope, just as Clerk Maxwell said (see p. 275). One more point about the ring: it does not always appear to us in the same aspect; sometimes it is open and sometimes it closes up until we see it edgeways, and then it disappears altogether. This shows how very thin it must be, and we can infer that the little satellites composing it must be very small indeed. You might say they need only be very flat; but it is hardly likely that they would keep their flatness always in the plane of the ring when they are jostling round at different rates. It seems most reasonable to think that they are small in all ways.

Now please look at this diagram showing the distances of the planets from the Sun. We can only imitate them on a very small scale, of course. You remember that our Earth is about 93 million miles from the Sun; let us call this 10 inches or 10 millimetres or whatever we like. Then the other distances can be written down as follows—

	Bode's Law	Distance
Mercury	4 + 0 =	4
Venus	4 + 3 =	7
Earth	4 + 6 =	10
Mars	4 + 12 =	16
(Minor Planets)	4 + 24 =	(28)
Jupiter	4 + 48 =	52
Saturn	4 + 96 =	100
Uranus	4 + 192 =	196
Neptune	4 + 384 =	388

These are not the actual distances, but they are so close to them that the extra convenience of being able to remember them or to write them down outweighs the disadvantage of inaccuracy for many purposes.

The law which helps us to remember them was first stated by a man called Titius, and we ought to call it by his name if every one had his rights; but Bode made a sensational use of the law, and so it is generally known as Bode's Law. You can easily see what it amounts to: write down a set of 4's, and add



Saturn: photographed by Barnard in 1911, with the 5-foot Reflector on Mount Wilson.

to them other numbers which are doubled every time, beginning with 3 for Venus. The easiest way to remember it is to try and remember that the Earth's distance comes out 10; and perhaps also that Saturn is 100; from these two facts you could recover the law if you had forgotten it.

Let us spend a moment or two on the use made of the law by Bode, about the end of the eighteenth century. At that time there was a break in the series, for none of the minor planets had been found. Nowadays we know nearly 1000 of these little bodies; many of them are very tiny, only a few miles in diameter. They are probably made of the same kind

of stuff as our Earth, and reflect the Sun's light as the Earth and the other planets do; but being so tiny they cannot reflect much of it and are consequently very hard to see. Most of the brightest of them have probably been found by this time, but every year more and more faint ones are found, so that we scarcely know whether there is any limit to their number. As regards distance from the Sun, they differ considerably among themselves, but with one or two rare exceptions they agree to keep within the gap between Mars and Jupiter. Now in Bode's time this was a real gap since none of the minor planets were known, and Bode thought that there must be a planet to fill the gap. The idea of a number of little planets doing duty for a big one had not at that time occurred to any one: it was merely thought that there was one missing planet, and Bode set the police on the track of the culprit. This may sound a strange statement; what he actually did was to get a number of astronomers to agree among themselves to watch different parts of the sky for the missing planet; but the little band of searchers were jokingly called the "astronomical police," so that my statement is not far wrong. It must have been mortifying to them when the culprit was first seen by an outsider (sometimes that happens to our earthly police in spite of their vigilance). Another astronomer called Piazzi, who was not looking for the planet at all, happened to find it; he watched it for a few nights to be sure of it, and sent a note of its position to a brother astronomer—one of the "police," but the post travelled very slowly in those days when there were no railways, so that it was a long time

before the other astronomer could look for the planet; Piazzi himself had fallen ill, and the planet, seizing the opportunity (almost like an actual thief with the crowd after him), dodged into the Sun and was lost to view. Perhaps you will not understand rightly what I mean by dodging into the Sun. You know how the Sun goes the round of the Zodiac: The Ram, the Bull, the Heavenly Twins, and so on (have you learnt that verse thoroughly?). As it visits them, each in turn disappears from view in the glare of daylight so that you cannot see the Ram in April, or the Bull in May. Indeed, not only one, but two or three of them are invisible at any given time of year. Now a planet moves about among the constellations: sometimes it is in one that is visible and sometimes in one that is lost in the Sun's glare; and Ceres, as the first-discovered minor planet was called, passed from one to the other very soon after the discovery. It seemed as though she had been found only to be lost again. You may say, could they not wait till she came out and catch her again? Yes, but sometimes it is very hard to tell when and where a burglar will come out if once you let him disappear. He may get on to the roof and crawl along to other houses, down through them and out at some back door, when the police are watching all the time in the wrong place. A planet is not quite so clever and erratic as a burglar; indeed, if we have watched his or her movements long enough, we can calculate almost exactly where he or she will be at a future time. That is what Kepler and Newton have done for us by finding out the great Law of Gravity which controls the movements. But everything

depends on that *if*; *if* we have watched her long enough. Ceres had only been watched for a very little time before Piazzi fell ill, and those who were accustomed to such calculations said it was not nearly long enough to enable the orbit to be calculated. You will understand the difficulty perhaps from Figure 42: if you have a large portion ABC of a circle given, it is pretty easy to find the centre O and draw the rest of the curve (dotted) from A to C. If the given part is much smaller, like DE, it is harder to find the centre P and draw the rest,

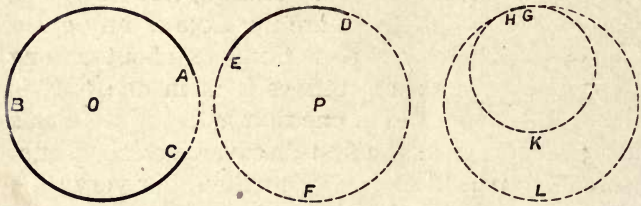


Fig. 42.

though it can still be done. But when there is only a tiny bit like GH given you, you scarcely know whether the circle should come out like GHK or like GHL: you may be watching for the burglar to come out at K when he is really at L. That was the difficulty about Ceres; she had only shown a very small bit of her circle before disappearing. Look at the minute spaces on your watch—there are 60 of them in the complete circle. If you had one of them drawn on a piece of paper, and one only, and tried from that to draw the whole watch dial, you would find it pretty hard; and Ceres did not even give the astronomers a whole space—she gave them less than

half a space! You will agree with me, I feel sure, that the man who showed them how to draw the whole dial in such circumstances was a remarkably clever man—a wonderful mathematician. His great book, in which he explained the method, his *Theoria Motus*, is one of those books which are likely to last as long as the world does. The little planet was found again, and to the astonishment of the world, another was also found in the search: and then two more—*four* burglars when the police had never suspected more than one! However, they were all securely handcuffed and tethered—that is to say, the mathematicians calculated their orbits very carefully, so as to know exactly where to find them when wanted—and the world settled down again after the excitement of the chase. I forgot to tell you that Ceres was first seen on the very first day of the nineteenth century, January 1, 1801; and the other three, Vesta, Pallas and Juno, were all found by March 1807. After that no more were found for forty years, and Hencke, who found the next, had been looking for fifteen years before he found it. Is that not strange when, as we know now, there are hundreds of these little planets in the sky? It shows the difficulties of finding them in the days before photography; since we have been able to take photographs, discovery is much easier; astronomers merely take a photograph of part of the sky, showing all the stars as fixed points, but if one of them seems to have moved or "trailed" during the exposure it is probably a planet.

But we must return to the more important planets, as I feel sure you cannot afford much time to visit

these tiny bits of rock. It is quite possible that they have their inhabitants on a small scale; they may be like dolls' houses, which are always most attractive; but we have to make calls at more important dwellings. The main point of our visit was to notice how the gap in Bode's Law was filled, and how it came in consequence to be called Bode's Law; and the next two big planets in the list have also something to say about filling vacant places. There were no more gaps to fill in the middle of the series, but we can have any number of places at the end. Before Uranus and Neptune were discovered the series stopped short at Saturn, with $4 + 96 = 100$; and it naturally seemed to confirm the law when Uranus was found by Herschel, and its distance was seen to agree closely with the next term, $4 + 192 = 196$. This had a good deal to do with Bode's formation of "the Astronomical Police."

I have already told you of Herschel's discovery of Uranus, when we were talking about his telescope. He thought at first he had found a comet, and it was not until after some time that the true nature of the discovery became clear. Then it created an immense sensation, for never before in the memory of man had any one found a new planet. All those previously known had been known for ages; they give their names to the days of the week, Satur(n)-day, Sun-day, Mo(o)n-day are called after Saturn, the Sun, the Moon. Our English names for the other days do not remind us of the planets, but the French names (Mar-di for Mars, Mercre-di for Mercury, Jeudi for Jupiter, Vendredi for Venus) are probably known to you. We have for some reason put instead of

Mars, who was the Roman god of war, the corresponding Scandinavian god of war Tuya, leading to Tuesday; and for Venus, the Roman goddess of love and beauty, we have substituted the Scandinavian Freya, leading to Friday. Perhaps as I have mentioned these days of the week I may as well explain the curious order in which they come.

The ancients did not know the distances of the planets away from us or from the Sun, but they could

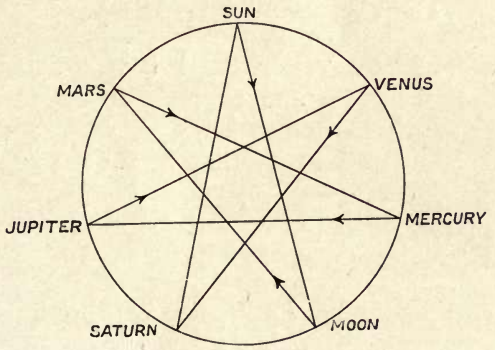


Fig. 43.

easily observe which of them moved most slowly and which most quickly. They put them in the order of speed, beginning with Saturn, the slowest, then Jupiter, Mars, the Sun, Venus, Mercury, and the Moon, which moves quickest of all (see Fig. 43). The old astrologers then assigned each planet influence for an hour; Saturn started with the first hour of his day, followed by Jupiter for the second hour, Mars for the third, and so on. When all seven planets had been used up, Saturn's turn came round again, and in the first 21 hours of the 24 all the planets

would get 3 turns each. Then Saturn, Jupiter, Mars would finish up the day, and the Sun's turn would come in the first hour of the next day. In Fig. 43 let us show that the Sun follows Saturn by joining up Saturn to the Sun by a line, missing two planets (Jupiter and Mars). Then to find what planet will rule the next day we miss Venus and Mercury and join to the Moon: miss two and join to Mars, and so on. If you follow round the star in the direction of the arrows you will find the days of the week in the right order, Saturnday, Sunday, Moonday, Mardi, Mercredi, Jeudi, Vendredi. I have begun with Saturday to make the explanation simpler; but you can see that one may begin anywhere; and the Sun is so important that they began the week with him.

Of course, when Uranus was found they could not upset so well-established an order as the days of the week to make room for him in it; and a very good thing it is they did not try, because there would have been another upset half-a-century later when Neptune was found.

That was a discovery even more remarkable than the discovery of Uranus, because it was made by calculation. We have already said that when a planet has been watched long enough, we can calculate just where it will be in the future; we must take into account, not only the attraction of the Sun, but that of other planets as well, since they are all pulling at one another. Though this is hard and toilsome work it can be done, and was done for the planet Uranus when it had been watched long enough. But the curious thing was that Uranus did

not follow the track calculated for it, and ultimately two very clever men, Adams, an Englishman, and Leverrier, a Frenchman, calculated that there must be a yet undiscovered planet pulling it out of the place; they independently calculated whereabouts this unknown planet must be, and in that position it was actually found.

One thing I would like you to realize is the very small indication they had to go upon. You know stories of scouts who have been able to track their prey by small indications, a bent twig here, a footprint there — indications which our untrained eyes would pass unnoticed? Well, the indications left by Uranus in his journey were small and faint like those, so that very clever scouts were required to read them properly. Suppose Uranus travelling in the circular path at the top of Fig. 44; let us put the real Uranus and the Uranus-as-it-might-be (undisturbed) both in their places; then you could not see the difference between them at all. More than that: suppose you magnify that circle on the screen 50 times, so that it becomes a big circle nearly the size of the room. We shall only have space on the screen for a little bit of it, which looks almost straight, owing to the

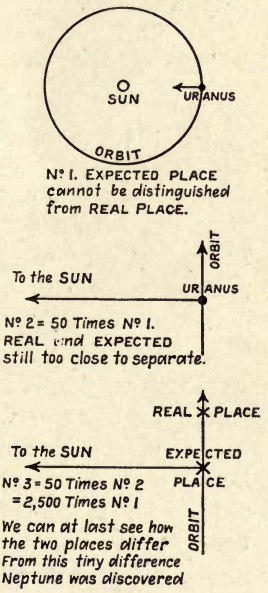


Fig. 44.

slow curvature. Even now you could not distinguish the real Uranus from the theoretical one in the calculated place. The disturbance can only be seen when that again is magnified 50 times; *then* you can just see the difference between the real and expected places. That small difference in the picture, diminished 2500 times, was all that Adams and Leverrier had to go upon, but from that tiny discrepancy they were able to infer the existence of the mighty planet Neptune.

Another point worthy of notice is that Bode's Law had by this time taken so firm a place in men's minds that both Adams and Leverrier used it to help them in their calculations. This is scarcely surprising when we remember that, first of all, Uranus had been found to fit in with the law; and that, secondly, the gap had been filled by the minor planets. But unfortunately this law, which they thought would be a help, was only a hindrance, for it no longer held. You may at some time or other have been going down a dark staircase, perhaps in some old tower, and the steps have been so even for a long time that you think you know just how far down to put your foot for the next, when suddenly there comes a short step or an extra long step which gives you quite a shock. It is often like that in scientific work: you think you have found out some law which will enable you to set your foot confidently on the next step, but owing to some unknown cause the next step is of a different length and you get a shock. Sometimes you can find out the reason for the exception, which soon leads to a discovery; sometimes the reason is not found for a long time. We do not

yet know why the steps in Bode's Law are so nearly regular up to Uranus and why there is then a short step to Neptune, but so it is; and both Adams and Leverrier, who confidently put out their feet for a step of the usual length, got a jar in consequence. It was not enough to make them miss the step altogether; in other words, they found Neptune all right; but the stumble was so obvious that it excited many remarks. Some people even went so far as to say that they had not found Neptune at all, but that the discovery was made by accident! It would take too long to explain the full meaning of this criticism; you may like to read all about it some day, especially if you like mathematics. But before leaving the story of this great discovery I should like just to tell you how it came to be connected with the names of two different people.

J. C. Adams was quite a young man who had just taken his B.A. degree at Cambridge when he carried out his resolution of calculating where the planet must be that was disturbing Uranus. He finished the calculations, and took them to the Professor of Astronomy in Cambridge. Unfortunately that particular professor did not happen to be very clever; sometimes there are professors who are not very clever, or are lazy, though you might not believe it, and it is hard luck on the students. However, this professor had enough sense to suggest that Adams should get help from some one else, and he recommended him to go to the Astronomer Royal (Airy) at Greenwich, and then he thought that he had done everything that could be reasonably expected of him and went peacefully to sleep. At any rate he

seems never to have enquired whether Adams went to Greenwich, or what happened to him there. He did go to Greenwich, but the Astronomer Royal was away in London on Government business; Adams called again later, but he was at dinner, and his faithful servants would not disturb him. The poor young man was getting a little discouraged, but he left a note of his results for the Astronomer Royal to look at after dinner. "According to my calculations," it read, "the observed irregularities in the movements of the planet Uranus may be accounted for by supposing the existence of an exterior body, the orbit of which is as follows." This note has been preserved and bears the date "October 1845" in the handwriting of the Astronomer Royal; for Adams himself put no date at all on this most important document, and Airy must have supplied it later on when he had already forgotten the exact day; so that we may judge he did not pay it very much attention at the time. But he did reply to Adams, asking him what he regarded as a test question. Adams got the impression that his careful calculations were mistrusted, and was so disappointed and heartbroken after all his work that he did not reply; and the whole incident dropped. It was the very greatest pity; a little more persistence on the part of any of these three men would have almost certainly led to the discovery of Neptune at once. Some one like Halley was wanted to keep them up to the mark; but no successor to Halley appeared, and the great chance was lost.

Meanwhile Leverrier had begun work on the same problem. He was already a famous astronomer and

published his results in a series of famous papers, ending up by pointing to the place near which Neptune must be. Now he pointed to very nearly the same place in the sky as Adams; as Airy found on comparing Leverrier's paper with the note he had received from Adams nearly a year before; and this made Airy think there must be enough chance of finding the planet to be worth trying. So he woke up the professor at Cambridge and told him to begin searching. The professor set to work, but was still half asleep, so that though he looked straight at Neptune more than once, he did not recognize it. Meanwhile Leverrier had set Galle, a German astronomer, to work (it is very curious how all these people set other folk to work instead of looking themselves, as they might easily have done), and Galle found the planet on the first night! You can well imagine that there was then a great fuss

The statue of Leverrier at the Paris Observatory.

as to whose planet it really was; everybody blamed somebody else, except Adams, who never blamed any one but himself for being too shy and easily discouraged. We need not follow the story further now than to say that it was at last honourably agreed to share the merit of the discovery equally between Adams and Leverrier. But I scarcely think we English have done enough public honour to the part played by Adams; there is indeed a plaque of his head in Westminster Abbey; but in the centre of the courtyard of the Paris Observatory there is a fine big statue of Leverrier, with head erect, pointing with his finger at a globe representing Neptune. "They order this matter better in France."

The plaque of Adams in Westminster Abbey.

We must now turn from the planets to their satellites. In one of the books which I mentioned at the outset, Mr. Griffith's *Honeymoon in Space*, it is suggested that instead of landing on Jupiter, which may still be so hot as to burn our feet, we should land on one of his satellites. We are not yet sure how many he has, but we know that he has at least eight.[1]

[1] A ninth satellite to Jupiter was discovered by Mr. Seth B. Nicholson in July 1914.

Four of them can easily be seen with quite a small telescope, and were seen by Galileo with the first telescope ever turned to the skies. The other four are very faint and were not discovered until recently. Just as Jupiter is so much bigger than our Earth, so is his system of satellites on a much grander scale than ours. Our model of the little Earth has our single Moon at a distance of 2 feet; but though one or two of Jupiter's satellites are about as near as this, others would be outside this lecture hall on the same scale, and one of them half-way down Albemarle Street!

Saturn has also a number of separate satellites besides the great crowd of little tiny ones which make up the ring. We know of nine or ten already (the tenth has been announced, but has not yet been satisfactorily identified), and they also are scattered to great distances from the planet himself.

If we chose to land on one of these satellites we should be liable to an experience which is quite unfamiliar on our Earth—that of a long eclipse of the Sun, when day would be turned into night. It is just possible to have a total eclipse of the Sun even on our Earth, but only for a few minutes. The Moon is not large enough to cover up the Sun for very long. Perhaps you have read an exciting book called *King Solomon's Mines?* When Sir Rider Haggard first wrote it, he introduced a total eclipse of the Sun which was quite impossibly long; it lasted (if I remember rightly) several hours, and the darkness was so great that the people could only grope their way about, being quite unable to see "their hands before their faces." Somebody must have told him this was all quite a mistake, because in later editions

of the book it was cut out. It has been my duty to observe a number of total eclipses of the Sun, but they never last more than a few minutes, and the darkness is not so great but that one can read a watch face. However, if we landed on one of Jupiter's satellites, we could see such an eclipse as Sir Rider Haggard describes; for instead of having only our little Moon to act as a screen between us and the Sun (see diagram on p. 232), we should have great big Jupiter, and he would cut off the light for a long time. We can imitate what would happen by using a model. The Sun's light is represented by a beam from the electric lantern, which lights up one side of the model and leaves the other dark. On the bright side it is day on Jupiter, on the dark side it is night. But the darkness does not merely affect the surface; it streams away in a cylinder or cone of shadow. Now I will take a billiard ball to represent a satellite, holding it by a string. While it is anywhere outside this cone of shadow it is illuminated by the beam much as Jupiter itself is; one side of it is bright and has daytime, the other side is dark and is having night time. But as I circulate it round Jupiter, it comes into this cone of shadow; the light of the beam is cut off, and there is a total eclipse, which lasts all the time the satellite is passing through the shadow until it emerges on the other side. Some of you may not be able to see this emergence because Jupiter blocks your view; but those in a different part of the room can see it quite well, and so could the others if they changed their position. In looking at the real Jupiter, we on Earth are constantly changing our position as the

Earth travels round the Sun; hence we can sometimes see the emergence and sometimes Jupiter blocks the way. You see the two kinds of blocking: he blocks the sunlight in one case, to make the eclipse; but he may also block the view from the Earth, if the Earth lies nearly in the same direction as the Sun.

There are two different cases in which the Earth may lie nearly in this direction; it may be on the near side of the Sun or on the further side; and because of the difference between the two cases a very important discovery was made, viz. that light takes time to travel. We know that sound takes time to travel because of echoes; we shout "Jack!" and after a perceptible interval a faint shout "Jack!" comes back to us from a distant wall or hill. If we measure the interval between shout and echo, and also measure the distance of the wall from us, we can find how quickly sound travels—about 1100 feet per second. Perhaps you have recognized this fact in another way; when there is a thunderstorm, we first see the lightning and we hear the thunder later. If we count the number of seconds between the flash and the first clap of thunder, and multiply by 1100 we can find how many feet away the flash took place. (As regards the rest of the thunder I suppose it is made up of echoes, partly at any rate.)

Now, has it ever occurred to you that the strike of a church clock never gives you the exact time unless you are close to it? If you are 1100 feet away you will not hear the strike until a whole second after it has occurred; if you are a mile away, you will hear

the clock nearly 5 seconds wrong! Many people set their watches by a big clock striking without thinking of this: perhaps 5 seconds is not very important to them. But now suppose a man had two houses, his dwelling and his office, let us say, one three miles away from the city clock, and the other only two miles away; and suppose his watch and the city clock were both keeping perfect time. Nevertheless when he was at home he would always think his watch was 15 seconds too fast, and when at his office he would think it was only 10 seconds too fast. The first time he noticed the difference, he might think his watch had gone wrong; but if he went on noticing he would soon find out that the watch was all right and that the discrepancy must be due to something else; and he would perhaps find out the real reason, namely, that the extra mile between house and office made the difference of 5 seconds because sound took that time to travel one mile.

In this kind of way it was found that light takes time to travel. For the striking clock we substitute an eclipse of one of Jupiter's satellites as seen from our Earth. For the dwelling and the office we substitute the two positions of the Earth, on opposite sides of the Sun, one far from the eclipse, the other nearer. The great Danish astronomer Roemer calculated times for the eclipses (which we may regard as his watch); and when he compared them with the observed times (which we may regard as the clock) he got a regular difference according as he was on the hither side (office) or the further side (dwelling) of the Sun, and he reasoned that light must take time to travel. Compared with sound, it travels fearfully

quick, no less than 188,000 miles a second, so that you might think the difference would be very small. But you must remember that instead of the single mile between dwelling and office, we have now the enormous distance between one side of the Earth's orbit and the other, about 186,000,000 miles, or nearly one thousand times the distance travelled by light in one second. Hence Roemer found a difference of nearly 1000 seconds or about 16 minutes, and in this way the velocity of light was found for the first time.

Now, you may say, that is very interesting as a story, but you do not see any particular good can come of knowing that light takes time to travel; such a piece of knowledge is quite remote from our practical everyday life. But very often scientific discoveries of this kind lead to practical results of immense importance. The great man whose statue is in the entrance hall, Michael Faraday, made discoveries as to the behaviour of little bits of wire and glass which seemed equally unpractical; and yet they led to our electric railways, and motor-cars, and aeroplanes, which could never have existed but for Faraday's discoveries made with little bits of wire in this Royal Institution. Another great man following Faraday, James Clerk Maxwell, noticed that the velocity of light, first detected by Roemer, was the same as a measurement made with the electro-magnetic apparatus due to Faraday; and he concluded that light was electro-magnetic in its action. And then another great man, Hertz, said, "If light consists of waves, and is electro-magnetic, then we ought to be able to get electric waves," and he found

out that he could; and his discoveries made wireless telegraphy possible. And so you see a practical discovery which you probably regard as one of the most wonderful of modern times can be traced back step by step to this discovery of Roemer's which seems entirely unpractical!

But we are getting rather away from the satellites themselves, in this talk about their eclipses, and I want us to think for a few minutes what a satellite really is. Why should there be these moons, these smaller bodies revolving round the planets? And indeed why should there be planets revolving round the Sun? For the same sort of answer will do for both these questions. The planets are satellites of the Sun just as our Moon is a satellite of the Earth and Jupiter's eight moons are his satellites; in all these cases we have reason to think that parts of the central body have become detached from it to form satellites. First of all remember that all these bodies are rotating—turning round on their axes. We proved that the Earth was rotating by the pendulum experiment in the first lecture; we can see Jupiter rotating by noticing his red spot; we can see the Sun rotating by means of sunspots, as we shall remark in the next lecture. Now, when a body is rotating, the outermost parts tend to fly off, and if they can be detached they will fly off. When a boatman twirls a wet mop, drops of water fly out in all directions. There are several pretty pieces of apparatus in the stores of this Institution which illustrate this principle. In Fig. 45 a weight A slides on a wire BC. A string DEFG attaches it to a hanging weight G. When everything is at rest the

hanging weight G drops to its lowest point, pulling the slider A towards the centre E. But now let us spin the apparatus about the vertical axis FK. The slider will tend to fly away from the axis and will pull up the weight G, unless we make G very heavy. If G is heavy enough it will hold A near the centre; but if it is not heavy enough A will fly

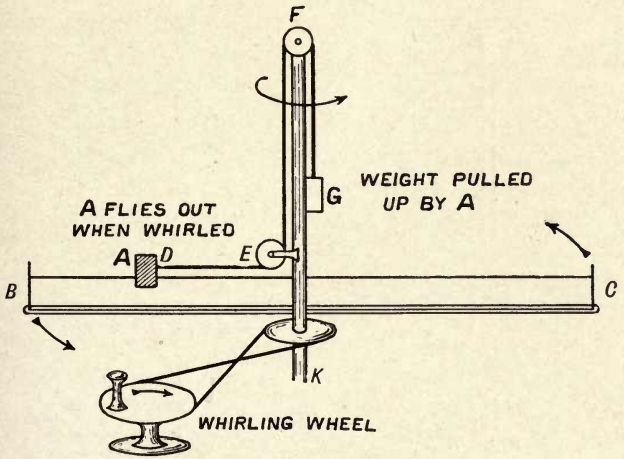


Fig. 45.

out. Whether G is heavy enough depends on how fast we spin the apparatus. If we spin it slowly, G will be strong enough to hold A in close; but as we spin faster and faster, A tries harder and harder to fly out from the centre and is at last too much for G. This is very much what happens in the formation of a satellite. If the parent body is spinning slowly, its gravity or attraction (which we have represented by the weight G and the string) will hold

all its parts in close together; but if for any reason the spin is made faster and faster, there will come a point at which some of the outermost portions will have a tendency to fly out too great for the gravity or attraction, and a satellite will be detached. We have still to explain why the spin should get faster and faster, and we will come back to that in a moment; but as we have the turn-table here, let us

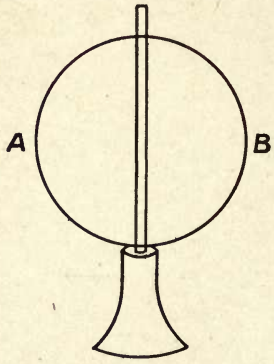


Fig. 46.

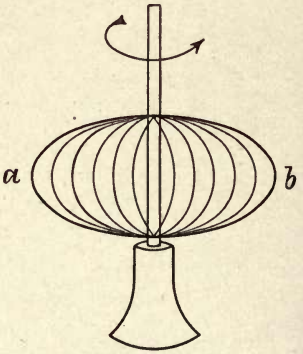


Fig. 47.

first do one or two more experiments. In Fig. 46 is a hoop, or rather a pair of hoops, which when at rest are circular, but flatten down as in Fig. 47 when they are spun, because the outer portions AB tend to fly away from the axis; you can easily see that in the second figure they are farther from the axis in the positions *ab* than in the first figure. The hoops are strong enough to hold together however fast we spin them in this case; but you must remember that I am not very strong and cannot spin very fast. If

we set machinery to work and buzzed the hoops round at a terrific pace we could make the portions *ab* break away and fly off. It is only a question of speed to break even the strongest flywheel.

Here is another experiment, which shows us something else. We generally say that the satellites go round the planets, as though the planets themselves did not move. But this is not strictly true. The Earth and Moon are like a pair of partners waltzing, one partner being very much heavier than the other. The little partner *almost* flies round the big one, but the big one has to move a little. Here is a big ball A and a little one B tied together (Fig. 48), and both are sliding on the same wire. If we put them at equal distances from the centre C and then spin the apparatus, the big ball immediately flies to the end *a*, pulling the little one with it. But if we put A at the centre (Fig. 49) and spin again, the little one flies to its end *b* and pulls the big one. If we are to get a proper balance we must put the big one, *not at* the centre, but certainly nearer than the

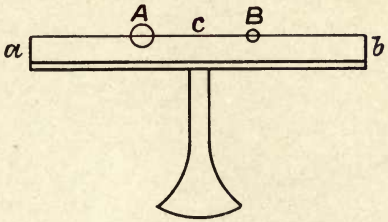


Fig. 48.

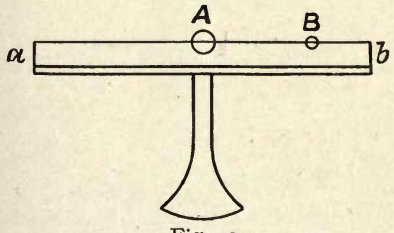
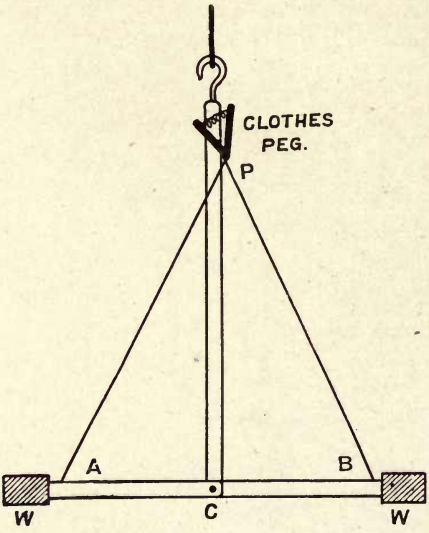


Fig. 49.

other; and if we try once or twice we can find a position when they are just balanced, so that neither pulls the other. It is quite a nice game to balance them. Now I think we have them. The little one is doing most of the revolving, but the big one is by



WEIGHTS (W. W.) EXTENDED

Fig. 50.

no means at rest, you see. So you must remember that our big Earth is itself waltzing a little with the Moon, though the Moon does most of the dancing.

Our next spinning experiment shall be a rough imitation of the detaching of a satellite. It requires some delicate adjustment, and you owe your thanks to Mr. Green for making us this mixture of alcohol and water, so carefully made that a little oil will

collect on the little table in the middle without wanting to go either up or down. Now Mr. Heath turns the table so that the oil is made to spin; and at once you see it flatten out as the hoops did. Now he turns it a little faster and—yes! there you see a drop of the oil flies off to form a satellite!

And so all we have now to consider is—why a planet should spin quicker. It was easy for us to make the oil spin quicker; all we had to do was to ask Mr. Heath to turn the handle a little quicker. But what turns the handle for a planet? Well, the simple reason is that the planet is continually shrinking with the cold, and as it shrinks it automatically spins quicker. We will illustrate that by experiment. In Fig. 50 two wooden bars, CA, CB, are loosely hinged at C. A string APB, passing between the jaws of a spring clothes-peg at P, holds the bars horizontal; and the whole is hung by a string and can be set spinning round it. To make the experiment more striking, there are two leaden weights at A and B. Now if the spring of the clothes-peg be nipped, the string is released and the ends A and B drop into the vertical position (Fig. 51). This is our way of representing the shrinking of the planet. We might make the bars CA and CB actually shorten themselves, but this is not easy to do, and so we make the weights A and B come near the axis in a different way, by dropping them downwards; the main point is that in the first position they are far out from the axis and in the second they are close to it. In the case of a planet, the shrinking may take millions of years; but to save time, we do it in a fraction of a second. Now I will spin the apparatus

slowly with the bars extended. Without interfering with the spin, I now nip the clothes-peg and the weights drop, when you see that the spin immediately becomes much more rapid. Shrinking towards the axis quickens up the spin just as well as telling Mr.

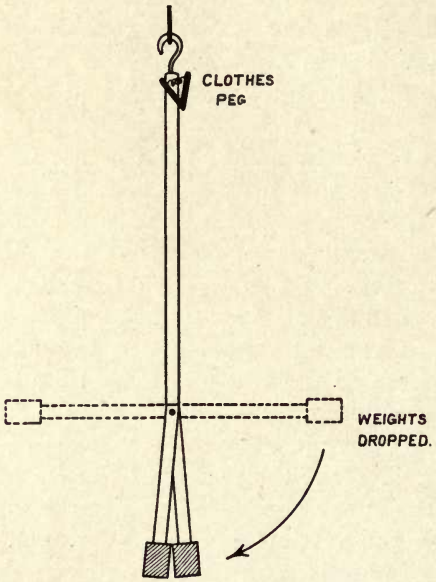


Fig. 51.

Heath to turn the handle quicker; and so we get our satellites formed because the planets shrink as they cool. There is another and perhaps a better way of making this experiment, using human arms instead of wooden ones. We place the human being on a turn-table (made to turn very easily by ball-bearings) with arms extended and holding a pair of dumb-bells (Fig. 52), and then give her a gentle

rotation. If she drops her arms (Fig. 53) she will at once spin much quicker.

I must now tell you about a very extraordinary discovery of quite recent times. I don't know whether you noticed that when we made a satellite

Fig. 52.

Fig. 53.

by spinning the oil, it went sailing round its planet in the same direction as the spin; and this seems natural. We should expect a planet spinning with the arrows (Fig. 54) to have a satellite like A, revolving in the same direction and not like B, revolving in the opposite direction; and yet, to our great surprise, such satellites have been discovered.

The story begins with the finding of Phœbe, the ninth satellite of Saturn, by Professor W. H. Pickering, of Harvard Observatory. He found it by examining photographs of Saturn, with the stars all round it; and as he was able to identify it on a number of such photographs taken on different days, he calculated an orbit for it so as to be able to find it again when wanted. You remember the case of the little planet Ceres, which had been observed for so short a time that astronomers despaired of finding it again, until Gauss showed them how to calculate the orbit even from a very few days' observations? Professor Pickering was luckier than Piazzi; he had quite enough observations to calculate the orbit—so he thought; but the trouble was that when he looked for the little satellite in its expected place (after the Sun had hidden it, as it hid Ceres) he could not find it anywhere! This was very puzzling indeed. Of course the little satellite *might* have been destroyed in the meantime by some unknown agency, but this did not seem likely; it seemed much more likely that he had made a mistake, and so indeed he had—the mistake of thinking that the satellite was travelling round Saturn in the usual way, like satellite A in Fig. 54. It is really travelling like satellite B, and when Professor Pickering persuaded himself, very reluctantly, to try this other supposition, he, to his great delight, found the little satellite in its calculated place. You may wonder why he made any supposition at all when he had actual observations to go upon; it would take too long to explain it here, but I may remind you that both Adams and Leverrier, in their cal-

culations to find Neptune, made the supposition that Bode's Law would go on in regular steps, and they too got led astray by this supposition. Suppositions are often made in such work, in order to simplify the calculations; but it would appear from these two cases far better to do without them if we can.

This discovery of Phœbe ultimately brought

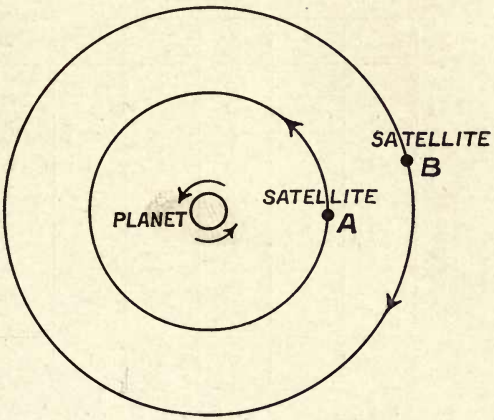


Fig. 54.

about an interesting situation. All the discoveries of satellites were at first made by other nations than England or America. Galileo started by finding four satellites of Jupiter, and it was not until nine in all had been discovered that anything was done in England. Once having started, however, England had the credit of seven out of the next eight, the other one falling to America. Then America continued with two satellites of Mars in 1877, a satellite of Jupiter in 1892, and Professor Pickering's

satellite of Saturn in 1899. Stimulated by this last, Professor Perrine, of the Lick Observatory, gave America the credit of two more satellites to Jupiter in 1904, making the score England 7, America 7, as you will see by the following table.

DISCOVERIES OF SATELLITES

Date.	Mars.	Jupiter.	Saturn.	Uranus.	Neptune.	
To 1685		4	5			Foreign
1787 1789	—	—	2	2	—	England
1848	—	—	1	—	—	America
1846 1851	—	—	—	2	1	England
1877	2	—	—	—	—	America
1892	—	1	—	—	—	America
1899	—	—	1	—	—	America
1904	—	2	—	—	—	America
1908	—	1	—	—	—	England
1914[1]	—	1	—	—	—	America
	2	9	9	4	1	

Score: Foreigners 9; England 8; America 8.

Now, who was to kick the next goal? I am glad to say that Mr. Melotte, of the Royal Observatory at Greenwich, scored for England by finding an eighth satellite to Jupiter in 1908. The Astronomer Royal has kindly lent for your inspection this beautiful model of Jupiter and his eight satellite orbits. The four found by Galileo are comparatively close to Jupiter, but the sharp eyes of Professor Barnard found one inside them—a very faint one—in 1892.

[1] The discovery of Mr. Nicholson in 1914 again brings the score level.

The other three are well away from these; Mr. Perrine's sixth and seventh are at nearly the same distance, and may be regarded as a twin pair. Then comes this tangle of wires far outside everything else, looking like a whole lot of orbits; but it is really only one orbit—that of Mr. Melotte's eighth satellite. The fact is that this satellite is so far from Jupiter that the Sun gets quite an undue pull upon it; it is like the man in the Bible who was trying to serve two masters, the result being unsatisfactory, as you remember. But it is even more important to notice that, like Phœbe, it is going round its planet in the wrong direction. We now know of three[1] such satellites; that of Neptune has been known to go round " retrograde " for a number of years, but as it was the single exception to the usual rule no one paid much attention to it. When, however, Professor Pickering found Phœbe, and especially when this going round in the wrong direction had been such a trouble to him, he looked for some explanation; and the one he suggested he illustrated by an experiment with a gyroscope, which we will repeat here. I have a gyroscope mounted in a wooden frame which I can grip firmly with both hands, or one of you can perhaps hold it after it has been set spinning. Now you see when I turn slowly in this direction (which is the same as that in which the gyroscope is spinning) nothing much happens; but if I turn round in the opposite direction, the gyroscope turns upside down. Try it yourself: you

[1] Since these lectures were given, a ninth satellite to Jupiter, also going round the wrong way, has been found in America. This makes four retrograde satellites.

must grip the frame firmly, because when the gyroscope turns over it gives you quite a shock and you must be careful not to drop it. The reason why it turns over may be put in this way: that it insists on spinning in the same direction in which the holder is turning. If he turns in the opposite direction, then the somersault of the gyroscope will practically make it spin in the other direction. You can verify this for yourself by turning your watch face downwards and imagining that you can see the hands through the back; you would see them moving contrary to their usual direction. People who go to the Southern hemisphere find the Sun going round the wrong way; that is because they have themselves turned upside down, pointing their feet in the direction of the heads of northern folk; and it would be the same if they remained at home, but the Earth turned a somersault.

Suppose now that the Earth did turn a somersault; the Moon would be going round us in the direction opposite to our rotation, like Phœbe does round Saturn. If, now, the Earth flung off a new moon, we should have two moons, going round in opposite directions. We explain the existence of Phœbe in this way: she is Saturn's eldest child, born at a time when he was turning on his axis in the direction which Phœbe now indicates. Subsequently he turned a somersault, and the other eight or nine children, all born after the somersault, naturally adopt the new direction. The only thing still to be explained is what made him turn the somersault, and Mr. Stratton has found a sufficient explanation of this in the action of the tides. We must therefore

suppose that our tides are tending to turn our Earth over again, though the action is so slight and so slow that we cannot detect it by direct observation.

The mention of our own tides reminds us that we have shamefully neglected our own Moon. We have been visiting other planets' satellites and neglecting our own child all the time. Jules Verne and H. G. Wells were very different : they spent all their attention on the Moon. Let us look first at some pictures of the Moon's surface, which is very mountainous. Now-a-days we can get such pictures by photography very easily, but before we had this great help it took a long time to make an accurate picture. A little more than a century ago a great artist, John Russell, R.A., spent about twenty years making a careful drawing which is still preserved at the Radcliffe Observatory at Oxford; we can now get as good a picture by photography in a second or less. Perhaps some of the fine detail would not be as good, for the human eye still beats the photograph in drawing fine detail; but the more conspicuous features would be more faithfully in their exact places. A photograph is wonderfully accurate and faithful, as can be proved by taking two photographs with different telescopes—say one in Paris and one in Chicago—and comparing the results. A great English astronomer whom we have recently lost, Mr. Saunder, had the most careful measures made on two such pictures and showed that they agreed extraordinarily well. Not only that, but he mapped out the surface of the Moon so accurately that in some ways we know it better than that of our own Earth. He gave one very striking proof of the accuracy of

his knowledge. The photographs sent to him all had marked on them the date and time when they were taken, but Mr. Saunder was able to say that in one case the wrong month had been given and in another case the wrong day! You can imagine that the astronomer who had taken the photographs did not like being told that he had made mistakes of that kind, and at first he was inclined to dispute it; but Mr. Saunder's case was too strong for him. Now, I want you to realize what this means: it is not as though anything were in a different place on the Moon itself from one day to another; so far as we can judge everything that we can see remains perfectly steady; otherwise Mr. Saunder could not make two different photographs fit. But on different days the Earth looks at the Moon from a slightly different angle, which can be allowed for if you know the correct date. If the wrong date is given, the wrong allowance is made and the measures will not fit those of other photographs. This was what Mr. Saunder found; but I need scarcely say that if his work had not been wonderfully accurate, he could not have found it out; and even as it was, it took him several days' hard work at his calculations, for all such work involves a great deal of arithmetic.

When we make a map of the Earth we may put in the places of the mountains without saying how high they are; but the best maps tell you the heights of all the hills. It is wonderful to think that we can also find the heights of the mountains and hills of the Moon, so that we can make not only a map, but a relief model. The Royal Astronomical Society has kindly lent us a beautiful relief model of a part of

the Moon's surface, with a model of the neighbourhood of Vesuvius alongside it, so that we can compare the two. You see that on the whole the Earth's mountains are distinctly smaller than those on the Moon. One reason for this is that our mountains are being continually washed away by the rain which falls on them, so that they are smaller now-a-days

Part of Moon.

Vesuvius and Bay of Naples.

From Plate VI of "The Moon" (Nasmyth & Carpenter)

than they used to be. On the Moon there is no rain, and so the mountains remain unwashed.

One way of measuring the heights of a mountain in the Moon is to measure the length of the shadow it casts. Of course a shadow does not always remain the same length; as you walk past a lamp-post you can see your own shadow grow shorter and longer; but if you stay in the same spot near the lamp it will remain of the same length; or if you go back to that spot it will come back to the same

length; or if any one were told where the lamp was, he could calculate the length. The lamp that casts the shadows of the lunar mountains is of course the Sun; and we can find his position at any date from the *Nautical Almanac* or a similar book, and then we can calculate the length of shadow if we know how high the mountain is; or, if we measure the length of shadow, we can calculate the height of the mountain. But there is one thing to be very careful about: if the plain on which the shadow falls is not quite flat we may be misled. We can see that by a

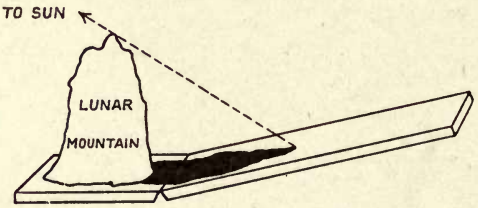


Fig. 55.

little experiment. Here is a rough model of a lunar mountain attached to a flat board, and from the lantern, which represents the Sun, we will cast a shadow on the board. But now the board is made up of two pieces hinged together, and if I slope the outer piece a little, you will see how the shadow alters in length; I can lengthen it or shorten it by a very slight inclination of the hinged piece (Figs. 55 and 56). I can, of course, see that I am sloping the board, and make due allowance; but on the Moon we do not know whether the plain is flat or not, so that when we measure heights in this way, we are liable to some uncertainties. The case is not

really so bad as I have made it appear to you; I have exaggerated things for the sake of plainness. One thing which helps us is that the Sun moves about, throwing shadows in different directions and of different lengths from the same mountain; so that if the supposed plain round the base slopes upward in one place and downwards in another, the lengths of the shadows will show it.

If there are mountains in the Moon like our own mountains, are there also inhabitants like those on

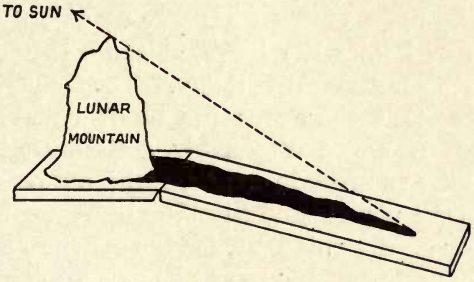


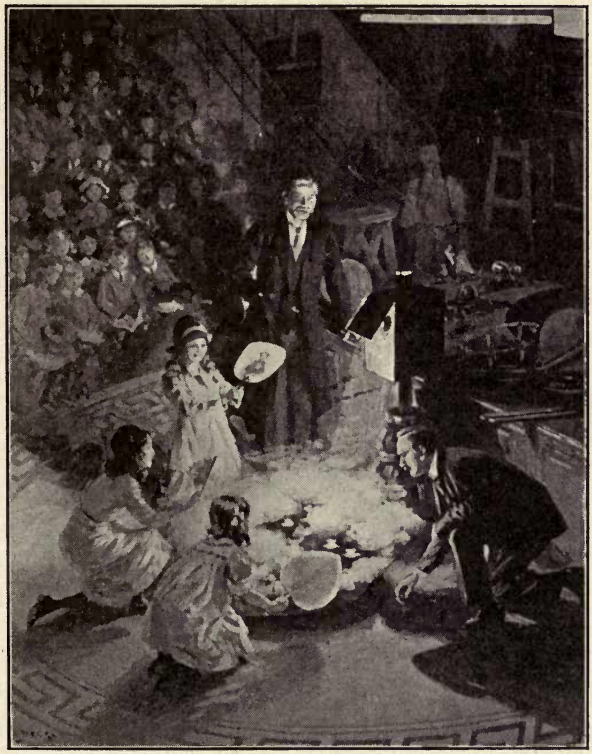
Fig. 56.

the Earth? At the beginning of this lecture we considered the case of Mars, and I showed you how hard it would be to see any signs of life on Mars by turning things round and supposing that we were looking at the Earth from Mars. You remember that we could not see violent changes in the British Isles even with the best telescope from that enormous distance. But the Moon is much nearer to us than Mars is: only a quarter of a million miles instead of (say) 50 million. If we use a telescope magnifying 1000 times, it is as though we were looking at things with the naked eye from 240 miles

away. You see that this is still a considerable distance; you would not expect to recognize much at such a distance. Some of you have been at sea and seen a ship on the horizon; you know how small it looks when it is five or six miles away, and how close it must come before you can see the people on its decks. You can well imagine that at 240 miles you might not see the ship at all with the naked eye—even a very big ship. We have as yet been unable to see any signs of life on the Moon, but that does not mean that there is no life; still less that there has never been any life. Perhaps life may by this time have disappeared from the Moon, as there is apparently very little air and water, if any. The Moon has dried up. But that there was life on it once I firmly believe. It seems reasonably certain that bodies which have so much in common with our own Earth, such as the planets and satellites of our system (and probably of other systems, for the stars are Suns like our own and probably have planets and satellites as our Sun has), have also life on them as our Earth has. It would be strange indeed if this peculiarity were confined to a single, rather insignificant body.

But whether there are men and women like ourselves on the Moon, or ever were, is quite a different question. Let me remind you what a vast number of forms of life there are even on our own Earth. There are fishes which live in the water; there are birds which fly in the air; there are insects which crawl and there are rabbits which live underground. Mr. H. G. Wells in his fascinating book has supposed that the inhabitants of the Moon are a combination of the last two classes; he makes them large insects

which live underground. Let me recommend you again to read his book, which will teach you a great



Liquid Air Experiment.
(See Notes to Illustrations.)

deal. His reason for making the inhabitants live underground is that there is certainly very little air on the Moon—some people say none at all, but Mr. Wells gives it the benefit of the doubt; he considers

that there may be none on the outside for us to detect, but there may be some in the interior; and accordingly he puts the dwellings down inside the Moon, so that the people can breathe. But he allows *some* air for the outside, and he brings it into the story in a very interesting way, all *frozen*. The "first men in the Moon" land in a regular snowdrift of frozen air, due to the fact that they land on a part of the surface on which the Sun is not shining, so that it is bitterly cold—so cold as to freeze the air. Not very long ago no one had ever seen air frozen or even liquid; but you fortunate young people of to-day can have it shown to you quite easily, and we will conclude this lecture with one or two experiments showing liquid air.

Here is a regular fountain of it at the back of the room. It is frightfully cold, and though it will not hurt you to put your hand in it for a moment, you could easily burn the skin off your hands by exposing them to it for too long. If we put an india-rubber ball into liquid air it is frozen so hard that it breaks when we throw it down. Even a flower dipped into liquid air becomes quite brittle. But perhaps the prettiest effect of liquid air can be seen by pouring some into a bath of warm water (see illustration). It makes a beautiful snowy cloud over the surface of the water. Now if some of the audience will kindly take these fans and fan away that cloud, they will find underneath little frozen cakes of air, bubbling furiously. One can show that they are cakes of air by the effect on a glowing wooden pipelight; we will light such a pipelight or a big wooden match: then blow out the flame, but leave the end glowing.

Now put the glowing end in the bubbles of one of the ice-floes and you see the flame burst out again. If the bubbles were water vapour this would not happen; they are really air, and the rush of air made by the rapid evaporation lights up the match again.

LECTURE V

OUR SUN

To-day we have to make perhaps the most important visit of all—a visit, as near as our telescope will allow us, to our Sun. Now, there are three special reasons why the Sun is so very important. In the first place it is the source, as you know, of all the light by which we see, very nearly all of the heat that warms us, and almost of the life that we live. We know how the plants live on sunlight—if there were no sunlight they would die; we know how animals live their lives when the sun is shining: during the night they sleep. On the half of our Earth not illuminated by the Sun the inhabitants are chiefly asleep: certainly most of the animals are asleep; and even human beings, especially children, are mostly asleep; if they do lie awake, they think the night is rather a dreadful time. Perhaps you have read a poem called "The City of Dreadful Night"? Those who cannot sleep generally long for the daylight. As the Earth turns round they are carried towards the place where the Sun rises; the birds begin to sing, the animals get up and begin to feed; boys and girls get ready for their breakfast and go to school and enjoy themselves, and have dinner about noon and go

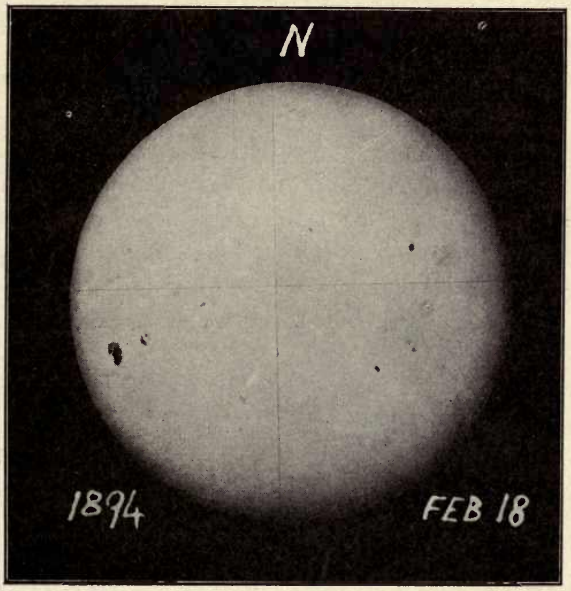
on with the other pleasures of the day : and finally, when bedtime comes, they plead for just another ten minutes because they know that going to bed means getting into the dark. They like to keep in the light as long as possible. Even if it is not merely a question of no Sun and full Sun (a question of night and day), when it is a question of much Sun and little Sun (summer and winter), you know very well which you prefer. When summer is coming the spring brings leaves to the trees, and little birds make their nests, and boys and girls begin to think of the summer holidays when they can go to the seaside. But when it comes near the winter—" the winter of our discontent," as Shakespeare puts it—then it is all cold; and many animals go into their winter quarters, perhaps to sleep. Human beings have by this time found many ways of alleviating the winter, especially by means of fires and lights, but we must remember that we owe even these to the Sun. Without the Sun in times gone by, those forests would not have grown which to-day give us our coal : the fires which we light in the winter are in many respects the work of the Sun. Hence it does not surprise us that in the old days they used to worship the Sun as a god. In our own country of Britain, the ancient Britons have left monuments, such as those at Stonehenge, showing the way in which the Sun came into their religion. There is one great stone standing erect at Stonehenge in a line with the sacrificial stone, so that the Sun at sunrise on one particular day in the year (June 21) just shines in a line over these two stones, and for a moment it

appears from the sacrificial stone as though the Sun stood on the top of the big one; and at that moment they used to make their sacrifice. We can still see to-day how impressive a sight that is, if we go to Stonehenge just at sunrise on Midsummer Day. I have not seen it myself, but I am told that hundreds of people assemble in their motor-cars to see this great sight.

Of course Stonehenge was not the only place where the Sun came into religious ceremonies. In ancient Egypt they worshipped the Sungod (Ra); and the Sun was used by the priests to consecrate the King in a very striking way, if we may accept the conclusions of some writers. Knowing how it would shine on a particular day, the priests built a special passage in one of the pyramids or temples down which the Sun would only shine just that once in the year, for a moment or two; and they used that knowledge to impress the people when they were going to appoint a new King. They would take the people into the Temple when the Sun was not shining; it was all dark. (At this point the lights in the lecture-room were extinguished.) Then they arranged so as to have the King in the right position, and at the proper moment the Sun would rise and the people saw their new King in the glorious blaze of sunlight! (At this point a beam of light was thrown from a special lantern to illuminate a small boy, dressed in kingly attire, who had been placed on the lecture table in the few moments darkness; his regal bearing was deservedly applauded.)

The first reason for the Sun's importance, then,

is that he is the source of our light and heat, and almost of our life itself. The second reason is because he is in a sense the father of us all. The Earth and planets are "chips of the old block" in the ordinary phrase. They are parts of the Sun



One of the regular photographs of the Sun taken at Greenwich.

detached from him in the manner we illustrated in the last lecture in talking of satellites. You remember that they were detached as the rate of spin increased. Now I want you to realize that the Sun rotates. You know how we showed in the first lecture that the Earth was rotating, and last Saturday we showed that Jupiter and the other

planets were all rotating; and now we have to realize that the great Sun is rotating on his axis also. That was first found out by Galileo when he observed sunspots. Here is a picture of the Sun as it is taken at the Royal Observatory, Greenwich, every fine day in the year. The two lines crossing the picture are the spider lines of the telescope; they tell us which is North and South: but all the rest of the bright part is the Sun. You notice that the edge is darker than the middle; and that tells us that the Sun has an atmosphere, of which we shall have more to say presently. You see also the spots, and you will please note their position on the first picture, which was taken on February 18; and now you will see how they have changed when we come to February 19, and again to February 20, and following dates. They do not move straight across horizontally because the Sun's axis is tilted; but careful measurement shows that there is a real axis, which has remained so far as we can tell in the same position since it has been investigated.

The path of the sunspot can be seen better if we make a "composite photograph" of all the days, by photographing them all on to the same plate. We can then see how the spots are travelling. From such a composite photograph I have made (see Fig. 57) a drawing showing the position of the big spot only and leaving out the others. The positions for the different days are numbered accordingly. On February 23, and again on February 25 and 26, the weather at Greenwich did not allow a photograph to be taken.

Before we go on to consider how the Sun's rota-

tion leads to the formation of planets let us say a word or two more about these spots. They were discovered, so far as Western peoples are concerned, by Galileo in 1610. The Chinese had noticed some

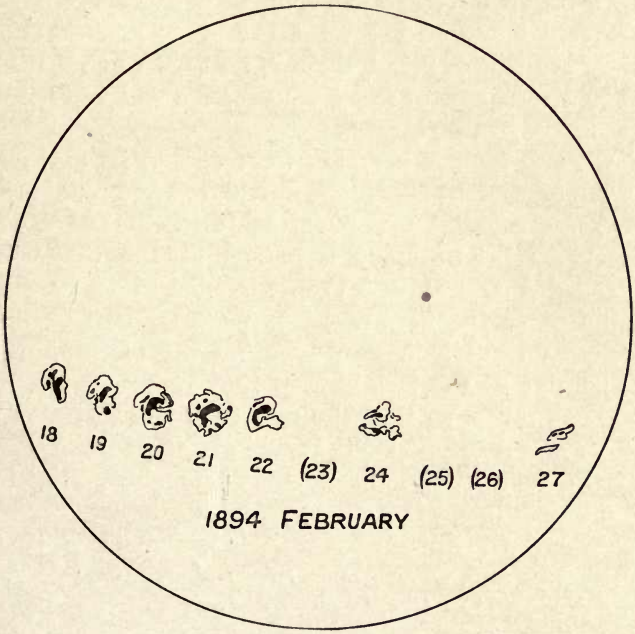


Fig. 57.—Composite drawing of a Sunspot from several Greenwich photographs.

of the large ones which can be seen with the naked eye from A.D. 188 onwards, but we had no knowledge of them at all till Galileo's time. Undoubtedly they are regions of fierce disturbance. Even in the old days, when Galileo first found them, the notion of disturbance or conflagration suggested itself, as

old drawings show. Later Herschel thought that they were holes in the bright surface of the Sun through which his dark interior could be seen; but the idea of the sun being a dark body surrounded by a bright envelope has long been given up. We scarcely know as yet what the spots are, or how they are caused; but there is no doubt at all that they are regions of fierce disturbance where terrible tornadoes are raging.

On one famous occasion (represented in Fig. 58) two independent observers, Carrington and Hodgson, saw an especially noteworthy disturbance. Two intensely bright spots appeared at the positions marked A and B, and then travelled in about five minutes to the new positions C and D. The distances do not look very large on the picture, perhaps, but on the Sun himself they represent nearly 100,000 miles, so that the rate of travel was about 300 miles a second! That will give you some idea of the fury of the storms that must be raging in the Sun.

A curious thing about these sunspots is that they wax and wane about every eleven years. At the present time (*i. e.* Christmas 1913–14, when these lectures were delivered) the Sun has been nearly free from spots for at least two years. It is what is called a time of "minimum." But we are expecting spots to begin again soon, and they will increase in number till they reach a "maximum," and then they will die away again to a minimum about eleven years from now: say about 1924, since we are already probably past the minimum. We have records which show us that this waxing and waning

has gone on at least during the last century and a half. Before that the records are too scanty to give us full or trustworthy information : people did not pay enough attention to the Sun. We must not be too ready to blame them because we our-

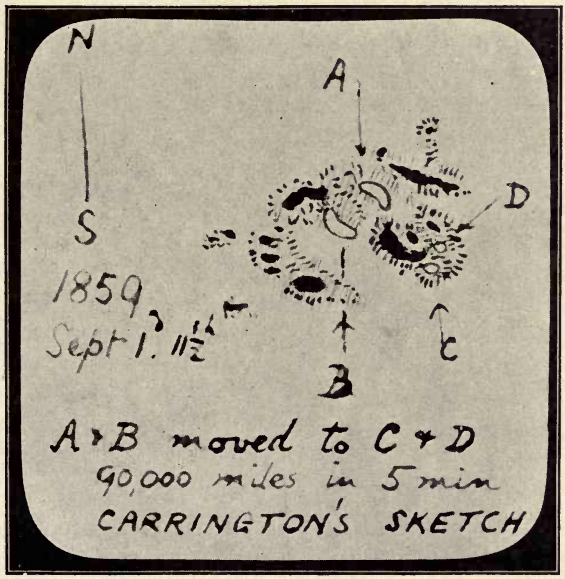


Fig. 58—A violent disturbance on the Sun.

selves do not pay nearly enough attention to him even now, considering his immense importance to us. Up till a year or two ago, no one had ever taken the trouble to make sure whether light and heat came to us from the Sun with strict regularity, or whether they vary in amount as the spots do. It has been calmly assumed that we can depend on

a strictly regular supply; but Mr. C. G. Abbot has now found out for us that this is not so: the light and heat do vary, and it is most important for us to watch the variations, considering that the future history of the world may depend on them.

But let us return to the spots and let us look a little more closely at the diagram (Fig. 59) showing their fluctuations. When the curve rises to a peak or maximum there were numerous spots: when it falls to a valley or minimum there were very few. The dates are shown along the bottom line every ten years. You will see that the interval between two minima is not always exactly eleven years: thus there is only about nine years between the minima of 1775–6 and 1784–5; but as much as thirteen years between the minima of 1811 and 1824. The variation is not regular, and there must be some reason for the want of regularity. I have been studying this matter specially for the last year and have found what I think is the key to the puzzle: I think there is a swarm of meteors revolving round the Sun, not in a nearly circular track like our Earth, but in an elongated track like that of a comet. I hope you remember the way in which a comet moves—loitering along slowly when it is far from the Sun, quickening up as it comes nearer, and whizzing round the sharp turn when it is closest to the Sun—what is called perihelion. Now I think this meteor swarm whizzes round so close to the Sun's surface that some of the meteors actually graze the surface and make the sunspots. The swarm is collected mostly at one part of the track, like a lot of people running

a race; but if it is a long race, such as a mile, we have seen some of the runners get far behind the leaders, sometimes a whole lap behind. If you stood inside the track close enough for the runners to graze you as they went by, you would be touched a good many times as the leaders went by, but only occasionally by the stragglers: and I suppose that the Sun is close up to the meteor track in this

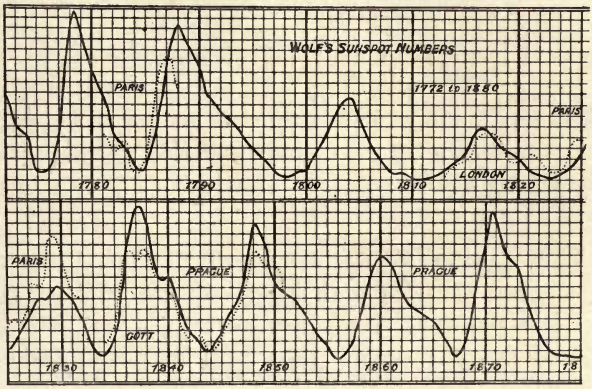


Fig. 59.—Waxing and waning of Sunspots.

way, so that he shows numerous spots when the leaders are going by and only a few as the stragglers tail off. But how does this notion help us to explain why the leaders should come round the track sometimes in eight years and sometimes in thirteen years, sticking a sort of average of eleven years? That is the really important point, and supplies the reason for putting forward this notion at all. Let me go back for a moment to Halley's comet. His attention was first drawn to the

probability that it would return by the figures for the years 1531, 1607 and 1682 being so much alike: he inferred that it must be the same comet running regularly round a track. Then he noticed that the returns to the Sun were not quite regular: there was an interval of more than seventy-six years between the first pair and of less than seventy-five years between the second pair. This was against him unless he could give a reason for the difference. With great acuteness he assigned the reason in general terms: he said that when the comet was far away from the Sun, loitering slowly along, any of the planets which happened to come by might attract it out of its course a little, upsetting the regularity of the return. It will do us no harm to look at his actual words—

> The motion of Saturn is so disturbed by the other planets, and especially by Jupiter, that his periodic time is uncertain, to the extent of several days. How much more liable to such perturbations is a comet which recedes to a distance nearly four times greater than Saturn, and a slight increase in whose velocity could change its orbit from an ellipse to a parabola? . . . I may, therefore, with confidence predict its return in the year 1758. If this prediction be fulfilled, there is no reason to doubt that the other comets will return.

Now, the meteor swarm which I consider responsible for sunspots can be pulled out of its course in the same kind of way as Halley's comet: and if we look for occasions when it was so attracted we

find plain indications of disturbance near the years 1766, 1799, 1833, 1866, 1899, which are a set of occasions already well known to astronomers from the great showers of meteors which were seen then. It has been shown that these showers are all due to a great meteor swarm called the Leonids, travelling round the Sun in about thirty-three years. My notion is that the sunspot swarm is disturbed by these Leonids every time they come round: I think that, as already stated, one end of the track grazes the Sun, but the other end is close to the track of the Leonids, so that it is particularly easy for the Leonids to attract the sunspot swarm, and to upset its regularity. Every time the Leonids come round we open a new chapter of sunspot history. Why should the end of the one track lie so close to the other? Of course we can say that there is no reason why it shouldn't, but it would be much more satisfactory if we could mention a reason why it should; and a very good reason seems to me to be that the sunspot swarm was broken off from the other near the point where they now approach so closely. Here again it is desirable to give a reason for the breakage, and here again we find one in the planet Saturn, which passes close to this same spot in its journey round the Sun (Fig. 60). It does not always meet the Leonids there, because when Saturn comes to the critical spot the Leonids may be in quite a different part of their track: indeed, they generally are. But about every 265½ years Saturn and the Leonids hit off the same moment for being at the meeting-place: and when this happens we find (by looking at the

Chinese records which go back nearly 2000 years, as I have already mentioned) that there is a new crop of sunspots. You will see, therefore, how I have come to suggest that a collision between Saturn and the Leonids causes meteors to fall into

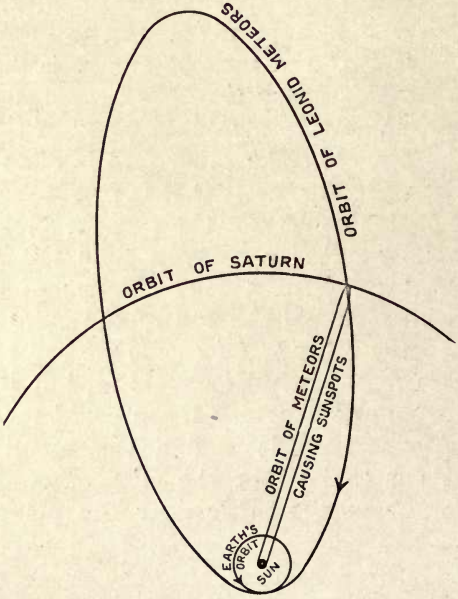


Fig. 60.—Suggestion for the explanation of Sunspots by a Meteor swarm.

the Sun and make sunspots. The idea is a new one and has attracted some attention : a clever draughtsman has illustrated it in the *Illustrated London News* (Fig. 61) ; I should myself have drawn the details rather differently, but his picture is certainly interesting. Let me give you another illustration

in words. On a ship when there is a head wind, the bows will sometimes hit a wave with a resounding smack, and a shower of spray is tossed into the air; the wind catches the spray, carries it down the boat, and dashes it in your face perhaps though you may be far away from the bows. In some such way I

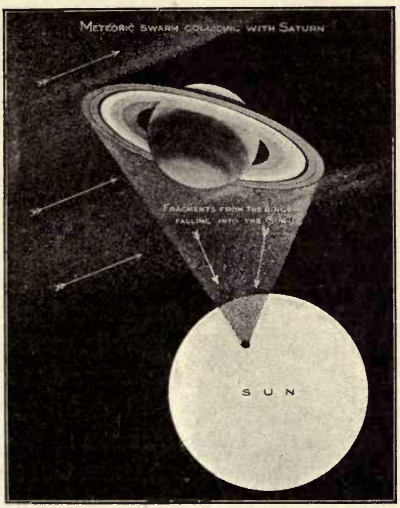


Fig. 61.

suppose Saturn and his Ring to hit the wave of Leonids: a shower of spray from the Leonids, or from Saturn's Ring, or from both, is tossed up, so to speak; is caught, not by the wind, but by the Sun's attraction, and is carried down to hit the Sun in the face, though he may be a long way from the scene of collision.

Let me tell you frankly that other astronomers have not as yet looked with a very friendly eye on

this idea: I think they will come round in time, though at present they have not done so. On the other hand, I may be mistaken, and some other origin of sunspots may be found. But in any case I hope you may have been interested to follow the course of the story, seeing how one idea leads to another. Unless we can get some chain of reasoning of this kind, which can be checked at various points, we cannot advance our knowledge: when, on the other hand, we can see our way to some check and find that it works, it gives us confidence that we are on the right road. It was a great pleasure to me when, having seen that collisions between Saturn and the Leonids ought to recur in about $265\frac{1}{2}$ years, I looked at the Chinese observations for the check, and found it very completely shown.

Although the particular idea I have just sketched is new, it is by no means a new idea that meteors should fall into the Sun. At one time it was thought that his heat and light were kept up in this way. If a shot is fired into a target, both shot and target are warmed. The heat comes from the stoppage of the motion of the shot. Do you remember our experiment to illustrate why meteors shine when they strike our air? We whirled an electric junction through the air and it became warm, because the air was resisting the motion and stopping it partly. If a bullet went right through the target and continued its course, nevertheless it would be partly stopped—it would scarcely continue its course so quickly as before: and we should get *some* heat: when the motion is wholly stopped we get more. Thus it was thought that meteors

attracted to the Sun and falling into him with tremendous speed, would develop enough heat to keep him going. You see, the Sun is giving out enormous quantities of heat; we get a good deal on our Earth, and some goes to Mercury and Venus and the other planets. But vastly more goes straight out into space because there is no planet in the direct line to catch it. From the amount our Earth receives we can calculate the total output, and it is truly terrific, enough to melt in a single second a solid column of ice two miles thick stretching from the Earth all the ninety-three million miles to the Sun. How is this outpouring kept up? One idea used to be that meteors fall in; but it was calculated that so many would be required that the Sun would grow visibly larger, which is not the case. Hence, though meteors may account for a part of the heat, there must be some other supply too. I must mention here that the Sun is not burning like a fire or a gas jet: it is glowing like an electric glowlamp. You know the difference between the two cases: a gas jet or candle gets quickly used up; but the filament of an electric light bulb, thin though it is, lasts for hundreds of hours without being consumed. The light comes, not from the consumption of the filament, but from the energy supplied to it from the electric power-house. The question we are considering is—what is the Sun's power-house, what is the source of the energy supplied which makes it glow?

The explanation considered sufficient until recently is almost the opposite of that we have just

considered. Meteors falling into the Sun would make it grow bigger: we believe, on the contrary, that it is getting smaller—"shrinking with the cold." That notion was mentioned in the last lecture in connection with the planets, and we saw how it led to the further notion that they would spin more quickly and ultimately throw off satellites. If, as we suppose, the planets themselves are satellites of the Sun thrown off in the same way, then at any rate he must have been shrinking in time past, and we know of no reason why the shrinkage should have stopped. But it seems extraordinary that we should try to explain his generous output of heat by saying that he is "shrinking with the cold": it looks as though we are explaining a thing by its opposite. We can, however, see how this may happen. Supposing your father were to come home one day and say to your mother: "I have been balancing accounts, and I find we have spent a great deal of money this year; we must reduce our establishment; let us give up our motor-car"; it might then happen that giving up the motor-car saved more money than was needed to bring the expenses down to the right figure, so that in other ways the family would be richer than before. It is rather like that with the Sun: losing a lot of heat makes him reduce his establishment—makes him shrink, but the very shrinking causes a development of heat—more heat, perhaps, than he lost, so that he is actually hotter after the shrinkage than before.

This way of getting heat by shrinkage does not appeal to our imaginations so readily as the idea of

getting it from fierce blows from meteors; but it is known to be just as real a way, and it can be calculated how much contraction is required to give out the heat we now experience. You might scarcely credit it, but the amount is so small that we could not have noticed it in the 200 years for which we have been measuring the Sun's size accurately. Until we had really good telescopes, (that is to say until the beginning of the eighteenth century), no measures could be made of the Sun's size sufficiently accurate to be worth considering. Hence we practically began measuring the Sun 200 years ago, and all the heat he has sent out during these 200 years could have been produced by his whole body shrinking ten miles inwards. Now, ten miles seems a long distance when we have to walk it, but it is quite imperceptible on the Sun, owing to his great distance. An inch is easy to see when close to us; but put an inch 135 miles away and how big would it look? Just as big as ten miles on the Sun. The Sun might have shrunk since astronomers watched him closely, not merely ten miles but even 100 miles without our being able to detect it.

Can this shrinking go on for ever? It is a hard question to answer. If it goes on steadily there must come a time when the Sun is as compact and solid as our Earth. At present we find that he is not solid, and not nearly so dense as the Earth. But even our solid Earth is still shrinking, as we know from the occurrence of earthquakes and the existence of mountains and valleys. When an orange dries and shrinks, its skin goes into folds :

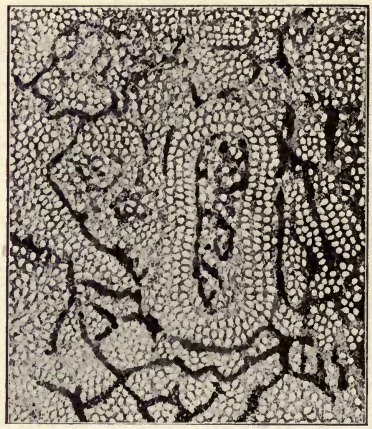
and so does the skin of our Earth as it shrinks. The mountains and valleys are the crinkles: the shrinkage is always trying to crumple them closer together with a stronger and stronger grip: they may hold out for a time, but at last they give way suddenly and then we have an earthquake. If we knew how much our Earth shrinks each year, we might be able to look forward and calculate how much smaller it will be in a million years from now; but we do not really know enough as yet to make the calculation. Or we could look backward and calculate how much bigger it was a million years ago, or two million or fifty million: and similarly with the Sun. The case of the Sun is easier because we have something to go upon; we can measure the amount of heat he is now giving out, and that tells us how fast he must be shrinking, whereas we have no such information about the Earth. In that way Lord Kelvin calculated backwards and thought he could find how many million years ago the Sun could have started being a Sun at all. You see as you go backwards you must suppose him bigger and bigger until he is spread out so much that he would no longer be like a Sun at all, and Lord Kelvin thought this was about 100,000,000 years ago. But he was assuming all the time that the heat we receive all comes from the shrinkage: that wonderful substance radium had not then been discovered, and there seemed to be no escape from Lord Kelvin's conclusion. Since the discovery of radium, however, the matter has assumed an entirely different aspect; we have learnt of the existence of a new kind of power-house

for supplying energy, namely the breaking up of an atom, of which no suspicion had entered any one's head till recently. If, as we seem entitled to think, there is this kind of power-house available in the Sun, he need not be shrinking so rapidly—indeed he need not be shrinking at all. The calculations of Lord Kelvin are, in fact, rendered so much waste-paper, since they start with an assumption which may not be correct at all.

I am sure you would all like to see just one experiment with radium, as you have heard so much about it. We will charge up this electroscope so that the gold leaves stand apart from each other. If now I bring a little radium *near* it, they close together, showing that the electric charge has been removed, and yet you see I have not actually touched anything. The fact is that little particles are shooting out from the radium: they hit the gold leaves and carry off the electricity.

I must now come to the third reason for the Sun's great importance. The first is that he gives us light, heat and life in such profusion as led to its worship in old days. The second reason is that our Earth and the other planets are actually parts of the Sun, who must be regarded as our parent (as the Moon is our child), and the third reason is that he is the *nearest star* to us. The Sun is really a star: other stars are a very long way off; but the Sun is comparatively near. The actual distance is 93 millions of miles, and you may think that that is not very near; and indeed it would not be very near if we were to go by an express train. Suppose we travelled in a train at the rate of sixty

miles an hour we should take 175 years to get to the Sun. I suppose a return ticket at the ordinary British rates would cost us something under a million pounds. It is curious to think that the Earth is taking a journey three times as long as that every year without charging us a penny. We go round the Sun in the greatest comfort, with



Drawing of part of the Sun's surface by Sir W. Huggins.

sleeping compartments at night and restaurant cars during the day, moving so quietly along that we can play our games too. The big Atlantic steamers have broad decks on which children can play some few games; but the Earth has a far broader deck on which we can play every kind of game. We ought to be very grateful indeed for all these comforts and opportunities, and yet we scarcely ever think of them.

But there is something that takes us much

quicker than the Earth, and that is Light. If we agree to travel by the telescope, then instead of taking 175 years to get to the Sun, we need only spend eight minutes. Eight minutes is not a long time on a journey. Even when the whole journey

Nasmyth's drawing of a Sunspot and the neighbouring surface.

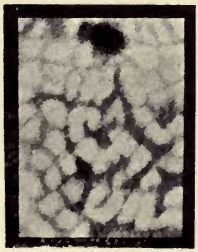
is only a few hours long, when we are within eight minutes of the end your mother will probably say, "Now, children, get your wraps and things together: we are just there." And so every one collects their wraps and rugs. Why! I have actually seen people stand up for more than eight minutes at the end of the journey, with bags and umbrellas

in their hands, so little do they reckon of eight minutes. But even travelling by telescope, at the enormous speed of light, we should take years to get to the stars—very different from the eight minutes to the Sun. Hence you see how close the Sun is compared with any other star. He is so close that we can see details on his surface, whereas even in our most powerful telescope the stars are mere points of light.

Let us look again at some of the representations of the Sun's surface made at different times. Sir William Huggins, a great English astronomer, whom we lost recently, drew the surface as a kind of mosaic pattern, while Mr. James Nasmyth (the inventor of the steam hammer, of which there is a fine working model in the machinery museum at South Kensington—I hope you all know that museum) drew a pattern of what he called willow leaves. There is a good deal of difference between their pictures, but they agree in claiming that the surface is made up of numerous bright grains—another observer compared them to rice grains—packed fairly close together excepting near a spot. Small as they appear in the pictures, these rice grains or willow-leaves must be of enormous size in the sun, say 1000 miles long by 500 wide. That these observers were not deceived has been amply proved by photography, especially the photographic enlargements taken by a Russian astronomer, M. Hansky. By a tragic accident he was drowned while bathing, and no one else has paid the same attention to photographing these rice grains on the Sun; but he obtained a sufficient

series of pictures to show us at what a great rate they are moving about. Even in a few seconds the pattern becomes quite differently arranged, as you can see by comparing one of M. Hansky's pictures with another. They must be moving

4h. 17m. 15s.



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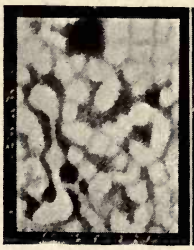

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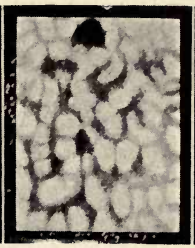

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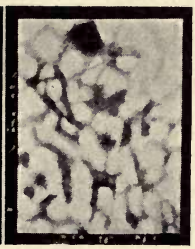


5h. 6m. 20s.

Hansky's photographs of a small portion of the Sun's surface, June 25, 1905.

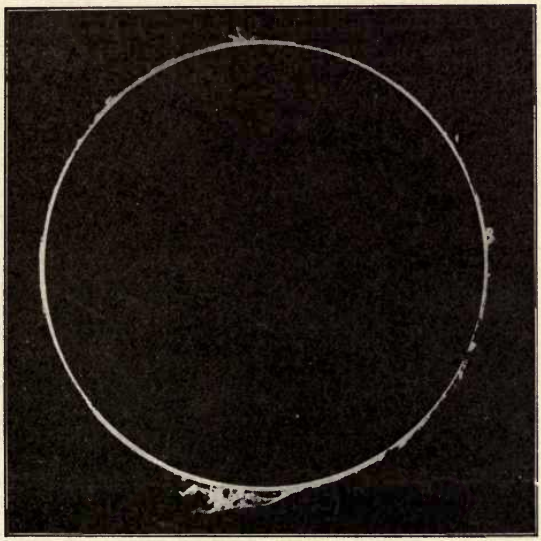
with great speed, some of them perhaps at 100 miles per second. We saw an instance of a great solar storm observed by Carrington and Hodgson; but we now begin to realize that the whole surface of the Sun is in a state of constant turmoil. We get another proof of this fact if we look at the edges

of the Sun, where we see great red flames shooting up to enormous heights. Perhaps we ought not to call them flames, because in our earthly fire-grates a flame means that something is being burnt, generally the gas from the coal which is being burnt up in the air. The solar flames do not represent anything burning; they glow like the filament of an electric lamp, but we have no better word to describe them than "flames."

We cannot see these flames in the ordinary way; but because they are of a special red colour we can see them by means of a trick. You remember our experiments with colours two lectures ago: we found that a red ribbon would show bright in the red, but in green light it appeared black; and do you remember how we lighted the room with the yellow light made by burning common salt, and then only yellow things showed bright? All other colours in a picture we were looking at—the reds and blues and violets—all disappeared. If we had taken a photograph in this yellow light, the yellow parts of the picture would have shown up, while the others would have been quite faint or altogether absent. And I then told you that this *trick* was used to take photographs, with an instrument called the spectro-heliograph, and with this instrument we can photograph the red flames round the Sun's edge; of course we use red light in order to show them up. The general plan is simply this: if we pass the Sun's light through a glass prism we have seen that it is spread out into all the different colours. Now let us block out all the other colours except the special red we want; for

this we need only a screen with a slit in it at the right place; all other colours will be stopped by the screen, but the special red will shine through the slit.

This special colour need not, of course, always



The " Red Flames " round the edge of the Sun.
(The whole of the ordinary Sun is blocked out.)

be red; we can alter the place of the slit so as to use any other colour we please, which is lucky, because red is not at all a good colour for photography. You probably know that you can have red light in the dark room without spoiling your negative. And, further, we need not only photograph the red flames at the Sun's edge, we can use

the instrument to photograph the details of the surface, which Huggins and Nasmyth tried to draw and Hansky succeeded in photographing in ordinary light. When we make pictures of them in special colours with this new instrument we get a different picture for every new colour. Let me show you a couple of such pictures of a small portion of the Sun's surface near a spot. The sunspot is a great

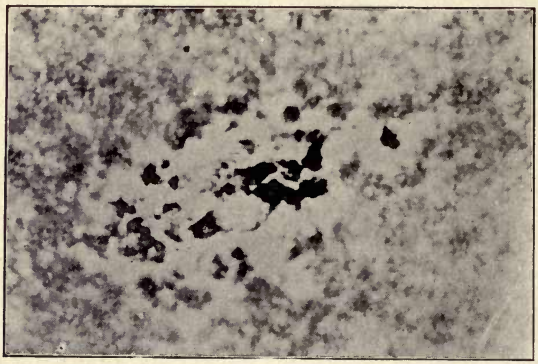


Fig. 62.—A Sunspot photographed in Calcium light (Oct. 9, 1903).

convenience in this case, because the pictures of the surroundings differ so completely that unless you had the spot to go by, you would scarcely believe that you were looking at the same part of the Sun; and yet it is exactly the same part, and the pictures were taken within a few minutes of each other; but in one the slit of the instrument was set for calcium light, and in the other for a special light made by hydrogen. You see how different they are; and I hope you understand the reason. Sup-

pose we made a letter picture of those last three words—

UNDERSTAND THE REASON	E E E	A A
Full Light.	Yellow Light.	Red Light.

colouring all the letters E with yellow, all the letters A with red, and the other letters green. Then if we took a photograph in yellow light we should get only the E's as in the second diagram; if we took a photograph in red light we should get only the A's. The two photographs would be quite different although we had actually photographed the same picture. Perhaps some of you have already taken colour photographs by the three-colour process; if so you will know about this principle without this explanation. The point is that just as we find out in one photograph where the letters E are distributed and in the other photograph the letters A, so in the case of the Sun we find in one photograph where the calcium is distributed and in the other photograph the hydrogen. Why should these two substances be arranged so differently? We get a hint of one probable reason from Fig. 63, in which we see a number of curved lines. There is no such regularity in the calcium picture; but the hydrogen picture shows these curves, which remind us at once of curves made by iron filings when near a magnet. Let us throw a picture of them on the screen. We first place a bar magnet on this sheet of glass and then

pepper some iron filings all over the glass. They do not go into a pattern at once, because even the smooth glass is not quite smooth; but if we tap the glass gently so as to make the filings jump up and down, then while they are in the air they feel the pull of the magnet and get a chance to obey it. He soon arranges them in the curved lines (see Fig. 64). Now if we were to scatter

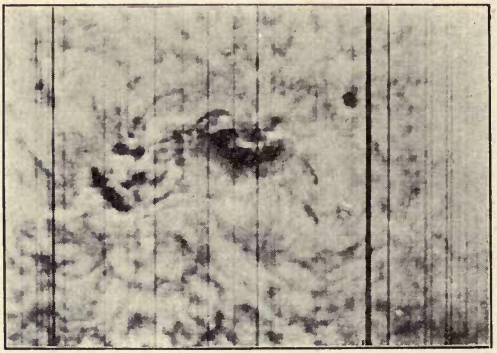


Fig. 63.—The same Spot as in Fig. 62, but photographed in Hydrogen light.

among these iron filings some filings of silver or other non-magnetic substance, the silver would not feel the pull of the magnet. Mr. W. S. Gilbert made a pretty song about the "silver churn" if you remember, in his opera *Patience*—

> "A magnet never by any endeavour
> Can attract a silver churn;"

and it is the same with silver filings; if they were scattered on the glass along with the iron filings, you might tap the glass as long as you like and

they would never get into curved lines; they would remain higgledy-piggledy. In the same way the hydrogen on the Sun gets into curved lines because it feels the magnetic attraction, while the calcium remains higgledy-piggledy.

But, you will ask, what is it on the Sun that corre-

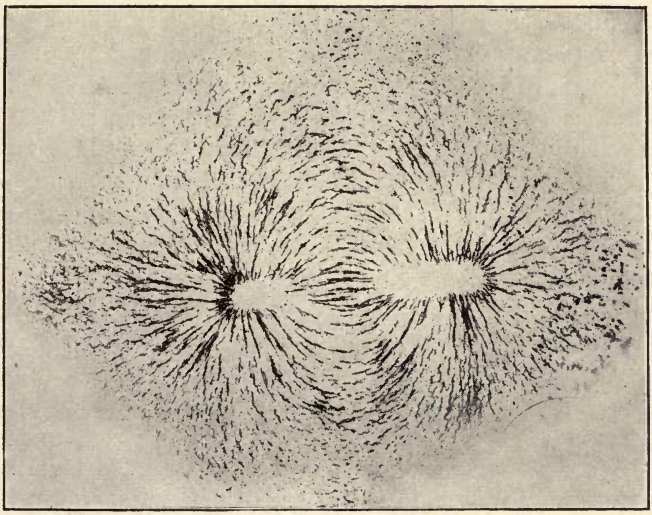


Fig. 64.—Iron filings near a Magnet.

sponds to the little magnet? and the answer has been given us in a beautiful manner quite recently, by Professor Hale, the great American astronomer, who has erected the Mount Wilson Observatory in California. His proof depends on experiments with polarized light which we cannot stop to explain just now, though I will show you some pretty experiments with it at the end of the lecture; but

the gist of the matter is that a sunspot is an electric whirlpool, which is as good as a magnet. Many of you know already what an electro-magnet is; if we take a coil of wire and send a current round and round it, the coil will attract iron filings in the same way as our little bar magnet. The wire may be made of copper and need not have any iron in it at all, though usually an iron "core" is added to make it stronger; but it would still act as a magnet if there were only the copper wire and the electricity circling round in it. Similarly, if we can get an electric whirlpool in any other way we shall have something which behaves like a magnet, and Professor Hale has shown that the sunspots behave in this way. Some of them are whirling in one direction and some in the other—he can detect the direction by the magnetic action. You know there are two ends to a magnet, often called the north and south poles, a whirlpool in one direction acts like a north pole and in the other like a south pole.

We shall not be able to describe Professor Hale's experiments, but I can show you some beautiful pictures taken by his assistant, Mr. St. John, with the spectro-heliograph, which show that a spot has the sucking action of a whirlpool. Have you ever read about the Maelstrom, the great Norwegian whirlpool? A boat which gets caught in it circles slowly round and round at first in the outer parts, but is always being drawn nearer and nearer to the centre, in a spiral. It is whirled more and more rapidly and ultimately sucked down at the centre, as though by some great octopus which waved its

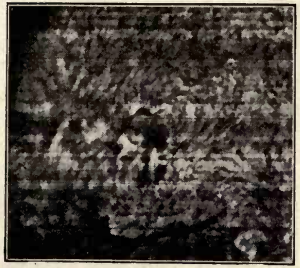


Fig. 65.—May 29, 1908.

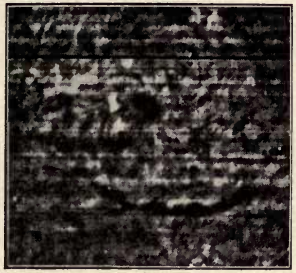


Fig. 66.—June 2.

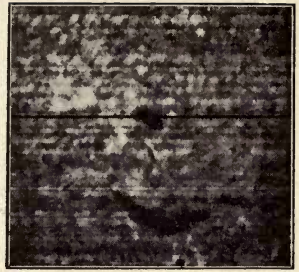


Fig. 67.—June 3, 4h. 58m.

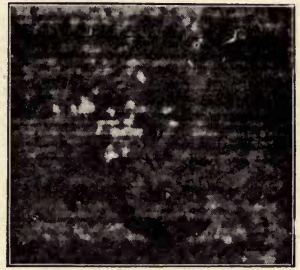


Fig. 68.—June 3, 5h. 14m.

Fig. 69.—June 3, 5h. 22m.

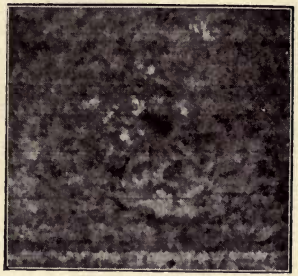


Fig. 70.—June 4, 6h. 12m.

long arms out and gradually drew the poor boat to its greedy maw. The pictures taken by Mr. St. John show us something of this kind. You see the sunspot, which is the centre of the whirlpool, about the middle of each picture, and near the bottom is an object which in Fig. 68 resembles a fish. At first this object is peacefully at rest, there being little change between May 29 and June 2, though the tail of the fish has turned towards the vortex: on June 3 this turning rapidly develops within a few minutes: it becomes clear that the fish is caught by its tail, and in Fig. 69 we see him being swallowed. Next day there is no trace of him (Fig. 70).

These actual proofs that a spot is a magnetic vortex are quite recent; but for a long time we have suspected some kind of magnetism in the Sun; indeed, it has been much more than a suspicion. Our magnets on the Earth are disturbed in a regular manner which corresponds closely to the ups and downs of sunspots; that was noticed half a century ago. But instead of calling your attention to these more or less regular changes, I will show you how beautifully Mr. Maunder proved that magnetic "storms" on Earth originate in some way in the Sun. These "storms" are quite irregular (like our storms in the weather), we should never notice them in ordinary life, but a telegraph clerk finds them a great nuisance; if they are violent and persistent they may make it impossible for him to send or receive his messages. At the time when Carrington and Hodgson noticed that great disturbance on the Sun, of which I spoke early in this

lecture, there was a furious magnetic storm on Earth, which was naturally attributed in some way to the solar disturbance. But now there is this difficulty: other disturbances in the Sun have been noticed without any corresponding magnetic storm on Earth; while on the other hand we have had storms which have driven the poor telegraphists nearly frantic while the surface of the Sun has betrayed no emotion whatever, so far as we could see. Hence, the question was in a very unsatisfactory state until Mr. Maunder made his ingenious suggestion. To explain the nature of it, perhaps you will let me first give an illustration of a more familiar kind. You know that when you are at the seaside the best time for bathing alters during the day, according to the tide. The time of high-tide falls later and later by about fifty minutes each day, because the tides are caused by the Moon and they follow it round. When the Moon has made a complete turn round the Earth, that is to say, in a month—the tides have changed by twenty-four hours, which comes to about fifty minutes each day. Let us make a diagram (Fig. 71) in which the twenty-four hours go from left to right, putting the days below one another; and let us mark the high tides, or the best bathing times on the diagram: there will be two of them each twenty-four hours, though one of them may come in the middle of the night when not many people want to bathe; but put them all down. Then the fifty minutes alteration each day will cause the marks to slope to the right. If we were to mark lunch time, which depends on the Sun, the marks would fall exactly below

one another, at the same time every day (that is supposing you *are* always in time for lunch); but since the tides depend on the Moon, the marks slope; and we could tell from the amount of slope that the marks referred to something depending on the

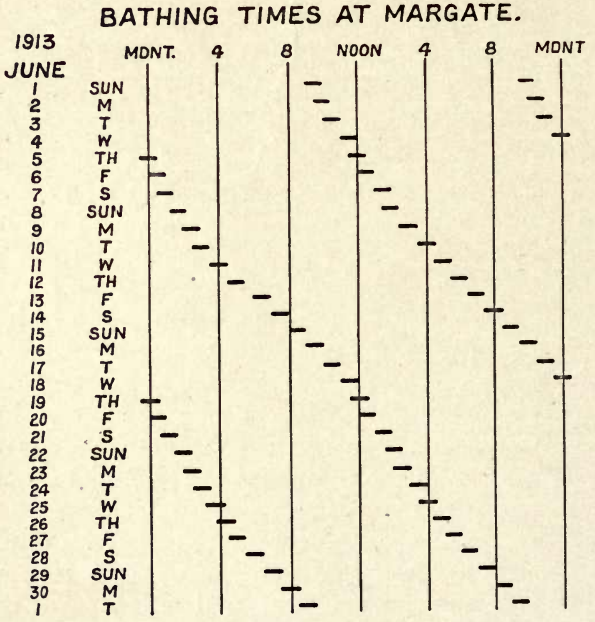


Fig. 71.

Moon, because in a month they go right through the twenty-four hours and start afresh. When the marks form a long series like this, it is easy to interpret the diagram.

We must notice just one more thing: the line is not quite straight, but rather wavy; this is

because the Sun also helps to cause tides, but you see the effect is small, and we will not notice it further.

But now suppose the series of marks is, owing to

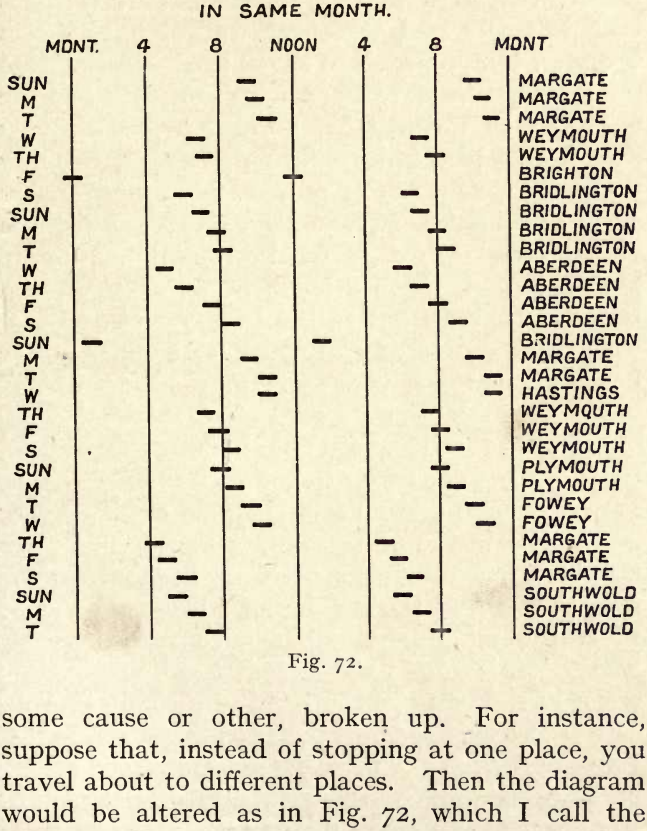


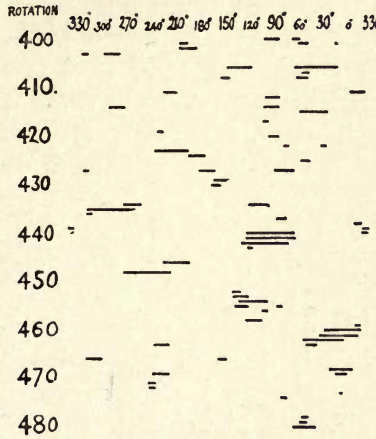
Fig. 72.

some cause or other, broken up. For instance, suppose that, instead of stopping at one place, you travel about to different places. Then the diagram would be altered as in Fig. 72, which I call the "American Tourist's Bathing Timetable," because

Americans have a reputation for never staying long in one place. So long as they stay anywhere, if only for three days, we shall get three marks in a sloping line of the right slope : even two consecutive days will give us the right slope; single days, of course, tell us nothing. The important point is that wherever and whenever we get a few days together, the proper slope shows itself, proving that the marks must have to do with the Moon in some way, though we may not be able to explain why they are so broken up unless we happen to know that they were made by an American.

Now I think we can follow Mr. Maunder's diagram of magnetic storms. Each horizontal line refers, not to the twenty-four hours in which the Earth turns on its axis, but to the twenty-seven days in which the Sun turns on *its* axis, as we saw at the beginning of the lecture. The marks show when a magnetic storm occurred on the Earth, and you will see at once that they are apt to occur in groups of three or four, one under the other. Whenever they are *exactly* one under the other (like the marks for lunch time in the other case), it means that when the Sun has rotated exactly once the storm is repeated, just as the striking of a clock is repeated when the minute hand has gone round exactly once. Mr. Maunder claims that the Sun stretches out a long finger like the hand of a clock, rotating as the Sun rotates; and that this finger strikes the Earth and causes a storm; goes round completely once, strikes the Earth again and causes another storm, and so on, until the finger changes its place like the restless American tourist. Some astron-

omers cannot believe in the possibility of the "finger"; but in any case it seems clear that *something* on the Sun causes the storm, because the storm is repeated when the Sun has turned round once. But you will no doubt notice that the marks are by no means always exactly one below another, though they may be nearly so; sometimes there is



PART OF MAUNDER'S "MAGNETIC STORM" SHEET

Fig. 73.

a slope in one direction and sometimes in another, which means that the cause is recurring either a little more or a little less rapidly than the time for the Sun to go round. The real fact is that there is no one special time which we can assign as that in which the Sun rotates, because he is not solid. When you stand on one of these nice new escalators at the tube stations, all the platform moves together because it is made of solids; but a liquid stream

moves faster in the middle and slower near the banks, and the Sun is like the stream, rather than the escalator. At any rate the spots move quicker when they are near his equator, and slower near the poles; and the slopes of the groups of marks in Mr. Maunder's diagram correspond to the paces of different spots; there is no difficulty in finding a place on the Sun which would suit any of the slopes in the diagram. Hence he concludes confidently, and we may agree with him, that the magnetic storms on our Earth originate in some way on the Sun; and this alone suggests pretty clearly that the Sun himself must be magnetic, at any rate, in certain parts. Professor Hale has carried the story further and told us where to look for the origins. He has enormously increased our daily work in observing the Sun; for, to take only one instance, he has shown that we must photograph him not once a day only, as is done at Greenwich, but many times and in different colours, since each colour gives us a different picture. But then Professor Hale has also banded astronomers together into a great union for observing the Sun, as Bode banded them a century ago to discover the missing planet. This new company of "astronomical police" is to photograph the Sun in all sorts of ways as often as possible; they are scattered round the world so that when the Sun is hidden at one place it may be shining in another. At present there is a rather wide gap in the ring of observations; but we are hoping that either Japan or Australia or New Zealand, or perhaps all three, will establish solar observatories; indeed, a rich and generous man,

Mr. Cawthron, has already promised £30,000 to build a solar observatory in New Zealand; and the Australian Commonwealth have promised one for Australia; so that we hope the Sun will be presently under constant police supervision, and will not be able to have any disturbance of note without its being recorded.

But there is one part of the Sun which cannot be seen in the ordinary way, nor photographed even with Professor Hale's new instrument. The beautiful corona which surrounds the ordinary Sun can only be seen when there is a total eclipse of the Sun,

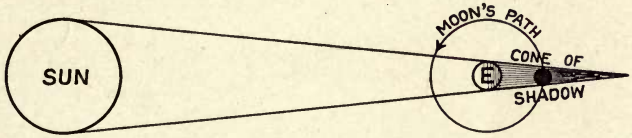


Fig. 74.—A total Eclipse of the Moon.

and that is a comparatively rare event in our experience. Most people have never seen a total eclipse of the Sun; possibly I am the only one in the room who has; and although I have seen several, I have had to travel many thousands of miles for the special purpose.

Many or all of you may have seen a total eclipse of the Moon, when the Earth comes between the Moon and the Sun and cuts off the Sun's light from it; the Earth is so much bigger than the Moon that it casts a shadow wide enough to envelope the Moon for an hour and more. You remember Jupiter's big shadow and how the little satellites disappeared into and remained in it for a long time

before they came out on the other side. The Earth's shadow is much smaller than that of Jupiter, but it is still large enough to swallow the Moon entirely. On the other hand, when the Moon comes between the Earth and the Sun, its shadow cannot swallow the Earth at all, it can only at best make a little dark patch upon it; if you can get within that dark patch you will see a total eclipse of the Sun, but it may not be easy to get there. The patch does not stay in one place all the time because the Moon is continually moving, and the Earth also is turning on its axis; the patch, there-

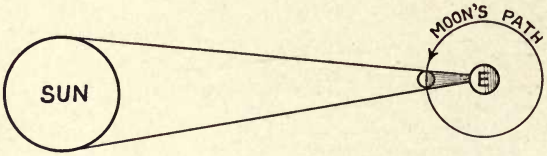


Fig. 75.—A total Eclipse of the Sun.

fore, makes a track on the Earth, and it may interest you to see the way in which these tracks arrange themselves on the Earth as years roll on. The movements of the Earth and Moon round the Sun are of such a kind that after about eighteen years they come back to *nearly* the same relative positions. If they came back to precisely the same, then, of course, the track would be exactly repeated in the same place; but the repetition is not so exact as this. Moreover, the interval is not eighteen years exactly, but eighteen years ten and one-third days, and the one-third of a day is important, because it shifts the track just one-third of the way round the Earth. You will see how the

track of 1824 is followed eighteen years later by the track of 1842 to the left, and that again by the track of 1860, and that by 1878. But now we have made three steps, each one-third of the way round; and we come back after fifty-four years nearly to the same place. We must keep putting in the

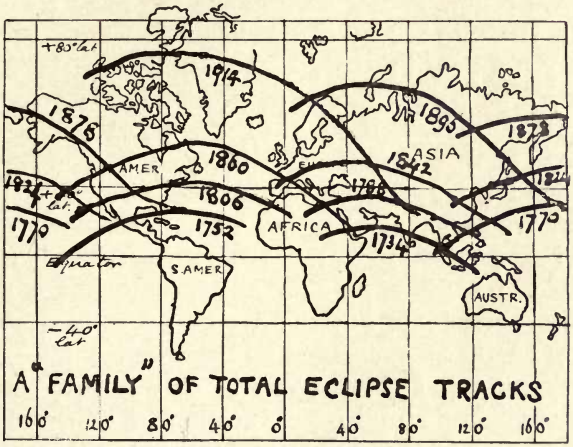


Fig. 76.

word " nearly," because none of these things happen exactly; you see that the 1878 track is just above the 1824 track, which has the 1770 track below it in turn. So that these tracks make a regular pattern on the Earth which we can almost draw for ourselves when we have got a few of them.

Since the tracks are edging a little further north each time, they will at last go over the edge of the Earth, at the North pole, and that family of eclipse tracks will be finished. It came in at the South pole 1200 years ago; travelled gradually

further and further north, and will disappear after 1932. There are altogether at any one time twelve such "families" of eclipse tracks; six of them are travelling northwards and six are travelling southwards. Every now and then one of them goes out at one pole or the other; but there is always a new family born about the same time to keep the number of twelve families complete. A few years ago, in 1909, a new family was born at the North pole which is of special interest to us. At its next return, in 1927, the track will come much further south and will cross the north of England (Fig. 77). So in thirteen years time you will have a chance of seeing a total eclipse without leaving England; you are very fortunate young people, for your parents and grandparents and greatgrandparents have had no such chance since 1724, nearly 200 years. You must be careful to be ready for it; I think you will only have twenty-five seconds of total eclipse; but still that will be long enough to give you a good view of the beautiful corona.

When the time is so short (twenty-five seconds is specially short, but even the longest total eclipse only lasts a few minutes) it is naturally important to make the most of it. Photography has helped us considerably in doing so, because we can arrange our cameras beforehand in exactly the right positions, and we can drill those who are to take the photographs until they can make the exposures quickly and without a mistake. A delay or a mistake would waste the precious seconds terribly; but the force of habit is so strong that after going

through the operations several times in rehearsal, the short time available is used to the very best advantage. The operations are as a rule quite simple, nothing more than opening a shutter at the right moment, and closing it; but even simple operations require a little practice to get them just right. We know the difference between a company

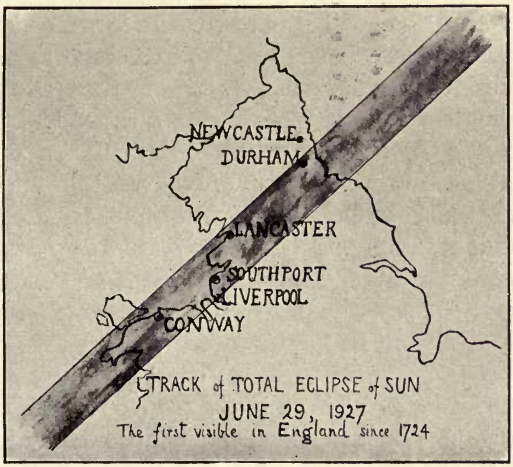


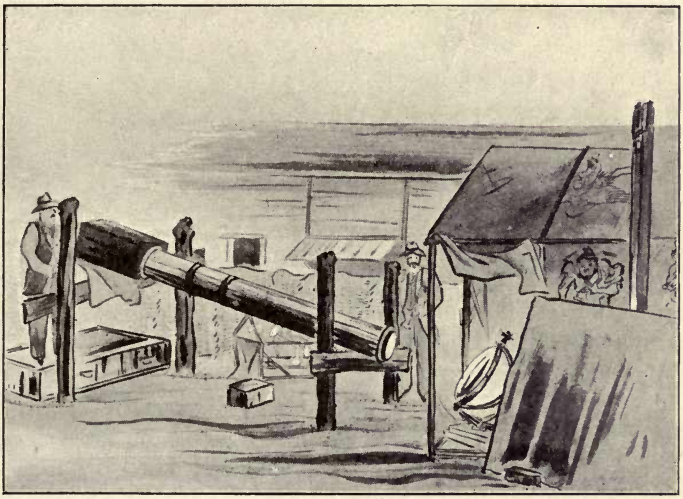
Fig. 77.

of recruits and the same people after they have been drilled a little; simple operations like "shouldering arms" are done clumsily at first, but smartly after drill. And after a man has learnt one kind of drill it is easier for him to learn another kind. For this reason the help of His Majesty's forces, naval or military, is specially welcome in eclipse work, and I am glad to say that it has on many occasions been very freely accorded. Eclipse tracks often

lie in such remote parts of the Earth that we cannot afford to send many astronomers there; but there are few parts of the Earth so remote that the help of British soldiers or sailors cannot be obtained; and with such help even a single astronomer may arrange his work so as to secure a number of valuable records.

To bring home to you the exciting nature of work of this kind, we will pretend to have an eclipse in this room. Here is the astronomer come to choose his site for observation (one of the "juvenile audience," previously instructed, here selected a site on the lecture room floor); he calls in the aid of His Majesty's forces (here several boy scouts entered the room) and directs them to erect his piers and instruments (the boy scouts now brought in a rough wooden model of a coelostat and telescope-camera and set them up on boxes representing piers). You see the astronomer proposes to use a coelostat—this mirror is to reflect the Sun's light into the camera. There is the Sun on our lantern-screen, and you see that the eclipse has already begun, for the edge of the Moon has taken a small bite out of the Sun's disc. It takes about an hour to cover the whole disc; we will not keep you so long as that, but while it is moving slowly across I will tell you what these gentlemen propose to do. The camera is pointed to the coelostat mirror in exactly the right position; and the astronomer is to take five photographs with different exposures. The first exposure is to be only for one second; this will suffice to show the brightest parts of the corona though not the faint portions; but even if the

eclipse only lasted one second before (say) clouds came up, the astronomer would have got *something* to take away. Hence, he puts that short exposure first. Next he ventures on five seconds; and then when he has got those two he ventures on a long exposure of forty seconds, so as to photograph the



The coelostat and telescope used by the Astronomer Royal in Japan in 1896.
(By a Japanese Artist.)

faint parts of the corona. A ten-second and two-second exposure complete the programme of five. Altogether, therefore, the camera will be open for $1 + 5 + 40 + 10 + 2 = 58$ seconds, and since the whole eclipse is to last 100 seconds it looks as though we might take more time than this; but you must remember that it requires some seconds to change the plate for the next photograph. There are four

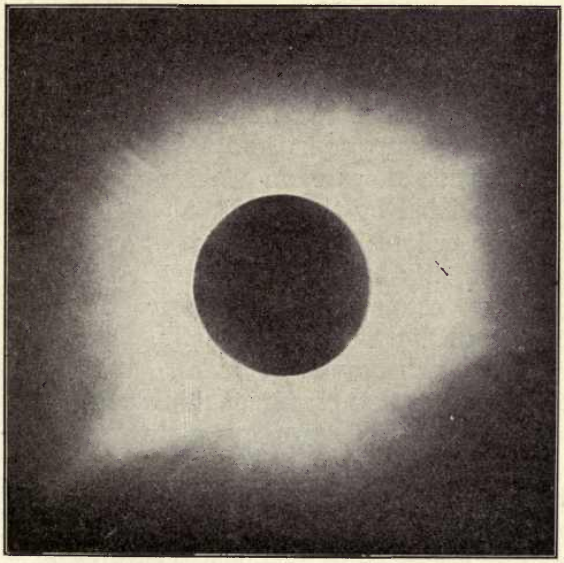
changes to be made, and if every change took ten seconds we should be running it rather fine. Fortunately the changes can be made more quickly than this. Special plate-holders are arranged which open like a hinged door instead of like a sliding door as usual; and to ensure rapidity the astronomer has two assistants, one to hand him each plate-holder when he wants it, the other to take it from him when exposed. In this way he can change plates in six or seven seconds. There are nevertheless a good many things to do in this time. After giving word to the man at the lens to put on the cap (which for eclipse work may be a light Japanese fan held in front of the lens without touching it) he must close the door of the slide, take it out of position and hand it to one assistant; receive the new slide from the other assistant, put it in place in the camera, open the door and (after, perhaps, allowing a second for the instrument to settle) give the word for the cap to be removed. With a little practice this can be done in six seconds, and these gentlemen have very kindly been practising this morning so that they may not fail to carry through the programme smartly this afternoon. One of them I have not yet mentioned—the time-caller. It is his business to look at a watch and call out seconds in a loud voice from the moment the eclipse commences, so that the astronomer may make the exposures of the right length, and know how time is passing. Thus suppose that when the astronomer has put in the holder for the fourth exposure of ten seconds, the time-caller is calling seventy-nine; the astronomer will know that he

must close the cap at eighty-nine; which leaves him eleven seconds in which to get the last exposure of two seconds. If, however, there has been an unfortunate delay anywhere, and the time-caller is calling eighty-five instead of seventy-nine, the astronomer realizes that if he gives the full ten seconds up to ninety-five, it will be practically impossible for him to get the last exposure of two seconds unless the eclipse lasts unexpectedly long (as *may* happen); he can thus shorten the exposure from ten seconds to five seconds if he likes, so as to make sure of the last plate. He has probably thought over what to do in such a case beforehand, for it is desirable not to leave such decisions to be made in the exciting moments of the eclipse.

Now I think I have explained the details, and the time of total eclipse is drawing very near, as you see. The daylight is perceptibly less (a few lamps were turned out), but it is by no means quite dark at a total eclipse; one can read the figures on a watch-face, though the time-caller may prefer to use a metronome which gives him the seconds by ear, and leaves his eyes free to watch the eclipse. By this time we ought to be feeling distinctly chilly; it has been said that a cold wind springs up about now, though others say the feeling is merely due to the fall of temperature. You know well enough the way in which it seems cooler even when the Sun only goes behind a cloud; at a total eclipse this effect is much more noticeable; and it must be admitted that there is a very solemn feeling about it all. Natives are often very much frightened; if they have not been told anything beforehand it

naturally takes them very much by surprise; while if they have been told, the tale has often come from the mouths of their superstitious priests, who tell it in their own way and for their own purposes. In India an eclipse is a specially good time during which to bathe in sacred waters; certain sacred pools used to receive such masses of bathers at an eclipse that hundreds of them were suffocated; but they died in ecstasy, believing the manner of death to be such as would ensure eternal bliss. Our careful English rule has changed all this by passing the bathers with great rapidity as through a turnstile, down into the water, and out again the other side quick, so that the next person may come—but even our tyranny has never contemplated *stopping* the bathing. Animals have no one to instruct them beforehand and are taken by surprise. In the next lecture we will have the kinematograph, and you will see how the hens go to roost when totality comes on and come running out after it is over. Even astronomers, who know exactly what to expect, feel the strain, especially in these last few minutes when there is nothing to do but wait, thinking over for the hundredth time whether everything is in exact readiness. Some of them may have dreamt the night before that the eclipse is beginning and they have nothing ready for it, and I can assure you that is a very distressing form of nightmare. But here you see we are all ready, and in a few seconds more the total eclipse will begin. I will ask you to keep silence, please, so that the time-caller and the astronomer's instructions may be clearly heard. Now!

[At this signal the picture of the round Sun on the screen, over which the dark Moon had been slowly creeping, was covered entirely up, while a representation of the corona was flashed out by means of a mechanical device in the slide. A few more lamps were lowered to represent the com-



The total Eclipse of 1898.

paratively sudden decrease of daylight as totality comes on. The time-caller counted seconds: one, two, three . . . in an even tone up to the 100 seconds agreed upon; the astronomer received the plate-holders (which were imitated in wood and cardboard), put them into the camera, called for an exposure of the required length and its close.

handed over the finished plate and put in the new one, all without a hitch or mistake of any kind. As a mere piece of drill the performance was warmly praised by a military man present in the audience. During the long (forty-second) exposure, the party of observers duly took the opportunity of regarding the corona, according to instructions; but for the rest of the time their " eyes were in the boat." At the hundredth second the corona disappeared with the reappearing crescent of the Sun, and the lamps previously lowered were relit; the eclipse was over; but all the photographs had been secured, with several seconds to spare, an achievement which was duly appreciated by the audience.]

Now the eclipse is over, and if our photographs are not properly taken we must wait till the next eclipse; we cannot repeat this one. Fortunately we have had fine weather—sometimes poor astronomers travel thousands of miles, get everything ready, and then it is cloudy or raining !—but I feel sure that when we develop our plates we shall find good pictures on them. And now what is the use of these pictures when we have them? Well, I cannot bother you with all the details of eclipse work, but I will try to give one or two illustrations of the way in which knowledge may be gained by the study of these pictures; and I will take the illustrations from my own work at eclipses, not because it is more important than that of other people, but because I know more about it.

I have been measuring the brightness of the corona at different distances from the Sun. Near the Sun it is very bright, as bright as the full Moon

or brighter. But it fades away so rapidly that at about a diameter from the Sun it is very difficult to see it or photograph it. When it is photographed you get dense blackness on the negative for the bright parts and hardly any effect for the faint parts. My work was to measure just how dense the different parts were; and the measurements are best made when the grades are not either too dense or too faint, but intermediate. Hence, you see why it is desirable to take photographs with different exposures; for by giving a long exposure you can make the fainter portions affect the plate more; it is as though they were not so faint. On the other hand, the short exposure of one second will suit the dense parts better.

But supposing these measures made, and the brightness of different parts compared, what then? What use will that be?

Well, we want to find out what the corona is made of; is it simply an atmosphere of gases like our own round the Earth, or has it solid particles in it, as our own atmosphere sometimes has in a fog? And again, is the atmosphere at rest or moving? If there are solid particles in it are they floating quietly, or are they being shot up out of the Sun with great velocity? Or are they, perhaps, falling continually into the Sun? If an eclipse only lasted long enough, we might perhaps answer some of these questions by watching the changes; but in the few minutes of a total eclipse the changes are too small to be noticed, and, by the time the next eclipse comes, everything has been altered past recognition. Hence, we have to work in other

ways. Suppose the particles are being shot up out of the Sun; then they will scatter as they go, like the sparks out of a rocket; and being more diffused they will send us less light per unit area. This will explain in a general way why the corona should be fainter as we recede from the Sun; but in science we must not be content with general explanations, we must see whether they fit particularly. We can calculate not only that the corona ought to be fainter but *how much* fainter it ought to be; and we can measure on the photographs *how much* fainter it is; and see whether the two "how much's" agree: if not, then our idea of the particles being shot up won't work and we must try some other idea, perhaps that they are falling continually down. When I tried these different ideas I concluded that the particles were behaving as a fountain behaves—both being shot up and falling down again. It would take us too long to explain why—all I want you to see is the kind of way in which we may learn about the corona from photographs at an eclipse.

But I have not explained why there need be solid particles in it at all. Why should it not be merely a mass of gas like our own air? That again can be answered from the photographs if we take them in what is called polarized light. I am afraid I am worrying you with rather hard notions this afternoon, or at any rate hard names; there is nothing very hard about the *notion* of polarized light, if you will think of a ray of light as a flat thing like a strip of cardboard which will bend quite easily sideways but not edgeways. I ought, however, to

compare a ray of light not to a single strip of card, but to a bundle of such strips with their edges in all directions, not a tight bundle, but a loose bundle in which one strip does not interfere with another. Now what would happen if we tried to bend the whole bundle in any particular direction? Some of them would have their edges turned in that direc-

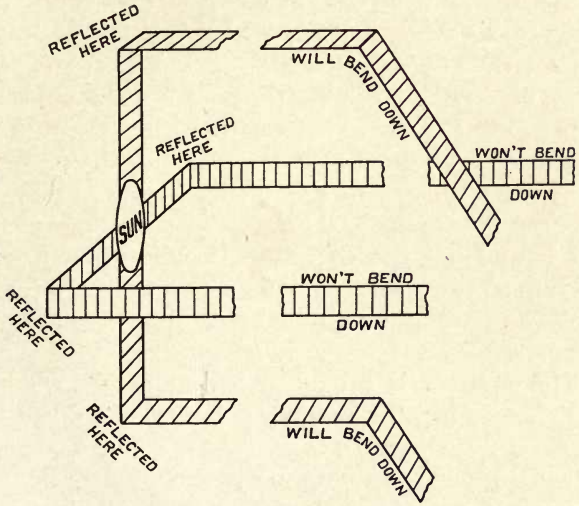


Fig. 78.

tion and would refuse to bend at all; others would have their flat sides and would bend easily; and we may say that after bending we should have only strips with their flat sides more or less in the right direction. So it is with a ray of light which is bent by being reflected from a solid particle. If there are solid particles in the corona, then we see them because the sunlight which shines on them is bent

or diverted to our eyes. In Fig. 78 I have tried to draw four rays of light like strips of cards; starting from the Sun in the middle and going out sideways from him, so that if they are not bent or reflected, they will never reach the Earth, which is supposed to be on the right of the picture. But I have supposed them to be reflected (by solid particles in the surrounding corona) at the places shown, and to come earthwards. Rays which are edgewise and cannot thus be reflected are left out of the picture. Now, on reaching the Earth, if we try to "polarize" these four rays by bending them downwards, the top and bottom rays will bend, but those at the sides are edgewise to this direction of bending and refuse. Hence in our "polarized" picture we should get light from the corona at the top and bottom of the picture, but not from the sides. Another picture with sideways bending would show the opposite.

The sunlight is originally a bundle of rays with their edges in all directions; but in the encounter with the solid particle those rays which are edgewise refuse to bend, leaving only the others, so that the ray is now "polarized" as it is called. If the corona is merely a mass of gas, the light will *not* be polarized. If the corona is partly gaseous and partly solid particles, we shall get some light from the solid particles which is polarized and some from the gas which is not. *How much* is there of each kind? Here again we come to the question of measurement, of finding out *how much* of a thing there is, and by arranging the particular photographs to be taken we can find it out by measure-

ments of the same kind as before, viz. of the density of the negative at different points. In Fig. 79 the

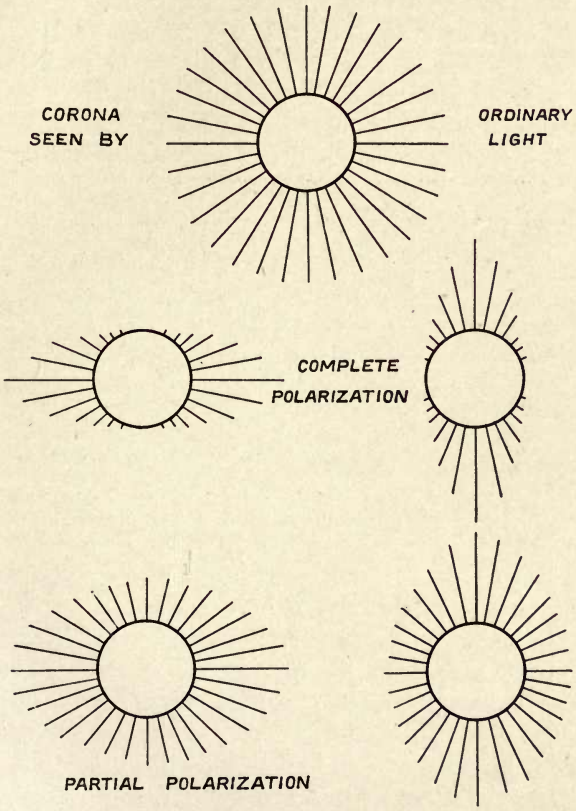


Fig. 79.

light of the corona is supposed to be equal in all directions as in the top picture. If on taking a pair of pictures, one polarized for bending right and left, and the other up and down, we got the

results shown in the middle, we should say that the polarization is complete. If we get a pair as shown at the bottom, we should say that it is only partial. The actual pair I got in Egypt in 1905 is shown in Fig. 80. My conclusion is that there are a large number of solid particles in the corona, because there is a great deal of polarized light;

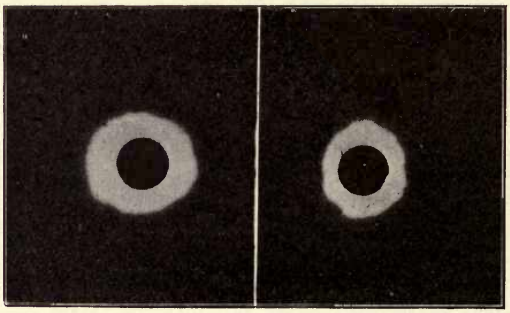


Fig. 80.—Two pictures of the 1905 Corona, polarized in perpendicular planes.

and other astronomers have found the same thing. And now, since you have listened so patiently to this tiresome explanation, I should like to show you that polarized light can give us some very pretty colours, which I am sure you will enjoy seeing.

[The lecture concluded with an exhibition of polariscopic effects from the magnificent collection of apparatus at the Royal Institution.]

LECTURE VI

THE STARS

We have now to make our longest journey of all—to the stars. Even as fast as the telescope will carry us it will take us some years to get there. It is difficult, perhaps, to realize that light seems to go quickly, yet really is taking time to travel; that really it takes time for light to travel, let us say, from me to you—not very long perhaps; but still you do not see me as I really am, but as I was a small fraction of a second ago. It is easier to realize the interval in the case of sound; and several times in this lecture I shall have to remind you of the likeness between light and sound, because it is so much easier to understand in the case of sound things which seem very difficult in the case of light. For instance, we all know that sound takes time to travel, because we have heard echoes. We shout, and presently we hear our shout coming back from some distant point. The time in between is the time taken by the sound to travel. When you look in your mirror in the morning, you really have to wait a little time before the light from your face goes to the mirror and comes back again, so that you get the echo or reflection from the mirror. I shall have something more to say about these light echoes towards the end of the

lecture. Light, then, takes time to travel, but the time taken is very, very small. I wonder how small a fraction of a second you think it takes to travel from me to you? Well, you know how long a year is; and how long a second is. Have you any idea how many seconds there are in a year? About 30 millions. Now suppose you pretend that a second is itself like a year; divide it into its seconds, that is into 30 million parts; one of these tiny parts will be about the time that what we may call a "wireless" wave of electricity takes to vibrate. I do not mean the time that the spark takes, but the time a single wave takes to be transmitted its whole length. And then suppose you take one of these "wireless" wave times, and divide *that* up into 30 million parts, you get about the time that a light wave takes to vibrate. And the time that it takes you to see me is about one wireless vibration, a very small fraction of a second, but still containing 30 million light vibrations.

We might make a new set of tables for you to learn—

30 million light vibrations make one wireless vibration.

30 million wireless vibrations make one second.

30 million seconds make one year.

And 30 million years—what do they make? Well, I shall have something more to say about that towards the end of the lecture.

For the present we will start with a year or two. It takes a year or two to get to the very nearest star, and many years to get, for instance, to most of the bright stars of the zodiac. "The Ram, the Bull,

the Heavenly Twins "—have you yet learnt their names and order?

These stars of the zodiac are comparatively bright and near. But there are many stars in the heavens which are fainter, that we cannot even see with the eye, especially those in the neighbourhood of the Milky Way. In Fig. 81 you see a very large number of stars, some of them big. Two of them are so bright that their light has made a kind of halo by reflection from the back of the photographic plate. That circle of light does not belong to the star; it is merely a photographic fault, showing how bright the star really is. But in the picture there are also many fainter stars, and even dark patches where there seem to be no stars at all. Now, do you think it is possible that there *are* no stars at all in those places? The photograph rather deceives us by being a flat thing; as though the stars were scattered over a flat surface; but that is not really the case. When Mr. *Daily Mirror* came and photographed us all the other day, his picture was also on a flat plate;

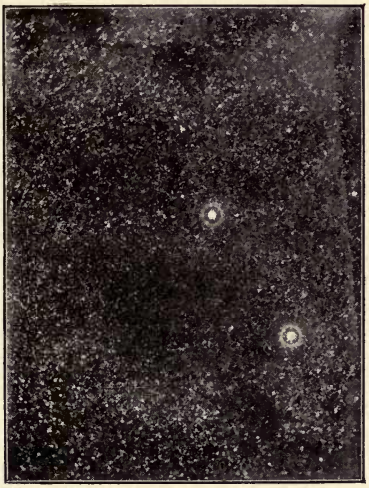


Fig. 81.—Region near the Southern Cross.

(The Cross is on the right, two big stars and two much smaller.)

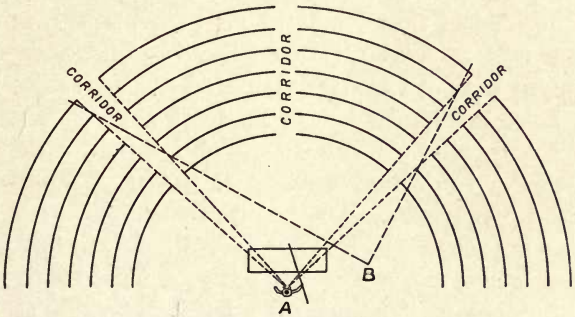
but that does not deceive us into thinking that this room full of people is flat. We know that there are some in the front row who come out big in the picture and some in the back rows who come out smaller. And so in the case of the stars; big bright ones are probably in the front row—near the Earth : the very faint ones in the back row. I say *probably* because we cannot be quite sure. Even in this room there are some very small people in the front row; and they come out small in the picture; while their grown-up parents may look large in the picture, in spite of the fact that they are in a row behind. In this case we can generally tell from the dress, or the character in the face, that the difference of size is due to age and not to the position in the room; but the stars do not help us in this way by their appearance, so that we are liable to mistakes if we assign their distances from us simply by the brightness.

But now what are we to think of the places on the photograph where there seem to be no stars? There are some directions in which I can see no people in this room, namely, when I look along the corridors : but I have to be careful to stand in one special place (A) to see this emptiness. If I move to the right, as to B, then I lose the appearance of vacancy in all three corridors (Fig. 82).

You can try a similar thing for yourselves with an empty tube. If you point it straight to your eye you can see the vacant space at the far end; but if you incline the tube, the far end disappears behind one of the sides. If the tube is short, you may have to incline it a good deal before the end disappears;

but if it is very long, the slightest tilt will make you lose the end.

Now, if these patches showing no stars are really vacant spaces, they must be like very long corridors or tubes pointed very straight at us: that they are very long, we know, because we have evidence that the stars extend to immense distances. The people in this audience are confined within a definite room—quite a nice, large room, it is true, but still a room



LECTURE ROOM SHEWING EMPTY SPACES FROM POSITION A, BUT NOT FROM B.

Fig. 82.

bounded by solid walls. There are no walls confining the stars: behind the front rows there are others, and behind them others still, and again others, and we never come to walls, so far as we know at present; so that the corridors through the audience of stars must be enormously long. Therefore, if we really see blank spaces at the end of them, they must be pointed *dead* straight at us, because the very slightest tilt would cause the end to disappear when the corridor or tube is so very, very long.

Now, can we think it likely that so many tubes or corridors or lanes through the stars should be pointed actually *dead* straight at our poor little Earth, or even at our tiny solar system? Here in this room the corridors all point at the lecturer, because he is a very important person. If there were no lecturer, I suppose you would all go away, wouldn't you? No lecturer, no audience! But we cannot think that our Earth, or our Sun, is of any particular importance to the audience of the stars—millions and thousands of millions of them, mostly far bigger and brighter than our Sun. In times gone by our ancestors thought that the Earth dominated the Universe; but we have gradually learnt modesty: nowadays we cannot think that the Earth and Sun are of any particular importance.

No! we must seek some other explanation of the blank patches; and it is not very difficult to find one. I can easily make a patch with no children visible by holding a screen in front of my eye. If the screen is near enough, quite a small one will do. A threepenny bit shuts out quite a lot of you. And similarly some kind of a screen, of dark nebulous matter, say, will easily explain any of these dark patches.

Hence we come to the conclusion that not only are there stars of the last degree of faintness, but there are in the heavens bodies of some kind not shining at all—"dogs in the manger," which not only do not shine themselves, but stop the light of other stars from reaching us. I don't know whether the argument seems to you convincing, but perhaps one or two other pictures may help it. Fig. 83

is a picture of a strip of nebula which seems curiously split down the middle. Here, again, we must remember that the nebula is not a flat object like a piece of paper, but a bulky object like a cushion. If there is a split, it must be a slice right through the cushion, and, besides this, the slice must be straight in the direction of the Earth. Both these difficult

Fig. 83.—Split Nebula in Andromeda.

suppositions are unnecessary if we suppose there is a dark streak in front of the nebula ; we may go further and presume that the streak is part of a flat ring surrounding the nebula, stopping the light where it passes in front.

Fig. 84 is a picture of a nebula of a different kind. You see a gauzy mass running down the picture with a bright edge : and you will see that the stars are much more numerous on one side of the

edge than on the other. It may be that they really are more numerous; but, if so, there must be a dividing wall pointed straight at the Earth, separating the region of many stars from that of few. It is much easier to believe that there is some obscuring stuff between us and the side which shows fewer

Fig. 84.—Nebula in Cygnus.

stars; so that the light of many of the faint stars is blotted out. If we count the number of stars within a given area on one side of the edge, and also the number in an equal area on the other side, we shall get a notion how many are lost by the stoppage of light.

This suggests that it may be of interest to count

the stars generally; and it is not only a matter of interest but of great importance. Let me take an instance from this room. You know how the front row is a little bit shorter than the next row and won't seat so many people; the row behind will seat a few more, and so on till we get to the back row, which will seat a good many. If we knew the distance between the rows we could count how many people there ought to be in each succeeding row. And it is very much the same in the case of the stars. If we count the bright stars, we know how many there ought to be of the next order of magnitude; and how many there should be next after that. Suppose we count them, and there are not so many—suppose we counted the outside row and found there were not so many people as it would hold, we would say, "Why this audience is beginning to thin off at the back!" So with the stars, we are inclined to think from the counts we make that they begin to thin off in the distance; and perhaps if we go far enough we should not find any more stars. Look, for instance, at this table [1] of the numbers of stars of successive magnitudes. Up to and including the second magnitude (let us say, the front two rows), there are 38 stars, and we can calculate (though I will not bother you with the details) that when we add the third row, or magnitude, we ought to have 151, very nearly four times as many; but we only find 111. Adding the next row, or magnitude, if 38 is right, we ought to get 603, but only find 300, and so on.

[1] Taken from Chapman & Melotte, Mem. R.A.S., lx. p. 163.

Magnitude.	Observed.	Calculated from 38.	Calculated from 32,360.
2·0	38	(38)	8
3·0	111	151	32
4·0	300	603	129
5·0	950	2,399	513
6·0	3,150	9,550	2,042
7·0	9,810	38,020	8,128
8·0	32,360	151,400	(32,360)
9·0	97,400	—	128,800
10·0	271,800	—	512,900
11·0	698,000	—	2,042,000
12·0	1,659,000	—	8,128,000
13·0	3,682,000	—	32,360,000
14·0	7,646,000	—	128,800,000
15·0	15,470,000	—	512,900,000
16·0	29,510,000	—	2,042,000,000
17·0	54,900,000	—	8,128,000,000

By the time we get to the eighth magnitude the numbers are so far behind the calculations that it seems useless to go further. But we can make a fresh start; let us assume that there is something peculiar about the first few rows—perhaps they are too closely packed, and let us start fair again with the eighth magnitude and the number 32,360 as shown in the last column. We can calculate both downwards and upwards, and we see that for the bright stars the calculations give fewer than there are, and for the faint stars many more.

We see then that the back rows are not properly full; and we get the idea that probably the stars do not go on for ever; they may not actually come to a sudden stop, as this audience does, owing to the walls of the room; because we cannot think there can be containing walls for the stars; but they seem to thin out and ultimately fail, as a small audience

might in a very big hall—front rows full, middle rows rather scattered, back rows quite empty. It does not need a great stretch of our imagination to think of a cluster of stars of this kind, for we have many instances in the sky; Fig. 85 is a picture of one for you to look at. Looking at them from outside

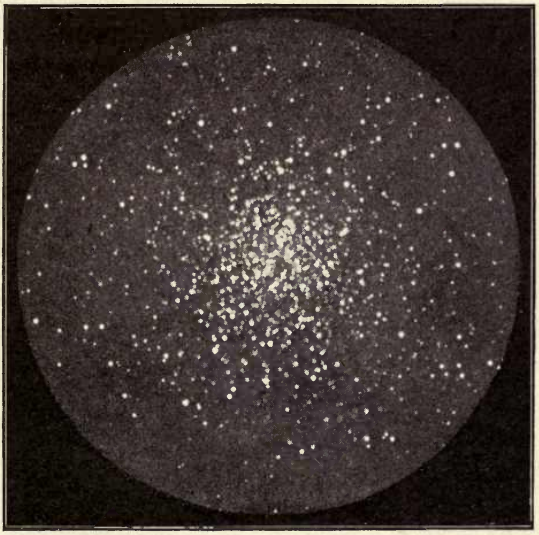


Fig. 85.—The Star Cluster in Hercules.

we can very easily see the way in which they thin out. When we ourselves are inside such a cluster, it is not so easy; but by careful counting of the different classes of stars, and reasoning upon the counts, we may be able to do it still.

But we must be *careful*, and there is especially one mistake of which we must be careful; a possibility of mistake at which I have already hinted. There

may be grown-ups in the back rows and small people in front : in other words, there may be very bright stars at a distance, and faint ones near to us ; and if we do not remember this, our inferences from the counts will be wrong.

Let me give you an illustration. Fig. 86 is a picture of three men. You say unhesitatingly that the big man is near us, the tiny man far away, and the middle man in between. You say this because men are all

Fig. 86.

nearly of the same height, and when they appear so very different in size as in the picture, the difference must be due to distance. So we think. But now I have deceived you in this picture by omitting certain details ; these are not men, but puppets hung on a Christmas tree, as you see in Fig. 87. They are really all at the same distance ; and their difference in size is real, because dolls and puppets can be as different in size as we like. What led us wrong was the quiet assumption that

the figures were those of men all much the same in size.

We must be careful not to assume that about the stars. They may vary as much as dolls or puppets in actual size; indeed we have found by experience

Fig. 87.

that they do, and here is one of the pieces of experience. Sir David Gill, now, I grieve to say, lying very ill with pneumonia,[1] picked out a number of stars of *about* the same brightness and actually measured their distance away by the method of

[1] Sir David Gill died on January 24, 1914.

"squint," or parallax, which we dealt with in the second lecture. He found the distances very different indeed; so that the actual sizes of the stars must be also very different.

SIR DAVID GILL'S DISTANCES OF FIRST MAGNITUDE STARS.

Name of Star.	Brightness compared with an *exactly* first magnitude star.	Parallax or "Squint."	Distance in "Light Years."	Diameter of star compared with α_2 Centauri.
Sirius . .	13	0·37	9	6
Canopus .	6	0·00	?	> 140
Rigel . .	2	0·00	?	> 75
α_2 Centauri	2	0·75	4	1
α Eridani .	1½	0·04	80	18
β Centauri	1	0·03	100	20
α Crucis .	1	0·05	64	11
Spica . .	1	0·00	?	> 55

In the first column is the name of the star: Sirius, or the Dog Star, I expect you have heard of, even if you don't know the others. In the next column you see that Sirius is not *exactly* a first magnitude star, it sends us actually thirteen times as much light as the standard which has been adopted as first magnitude, and others in the table are brighter than first magnitude. In the next column you see the amount of parallax or "squint"; but I expect you prefer to look at the column after that which shows that Sirius is nine "light years" away, meaning that light, travelling as we know at 186,000 miles per second, actually takes nine years to come to us from Sirius! Can you now tell how many *miles* away Sirius is? Remember that there are 30 million

seconds in a year, and you will find that Sirius is more than 40 billion miles away—using billion in our English way for a million million. (In France a billion means much less: they use it to mean only a thousand million.)

Now this is far enough in all conscience; but what are we to say of Canopus and Rigel and Spica? They are so far away that Sir David Gill could not find any "squint" or parallax at all, and had to write zero in the third column. If the "squint" had been as large as that for β Centauri, or even half as large, he could have measured it. These stars must be at least twice as far off as β Centauri, which is 100 "light years," or, say, 440 billion miles from us.

In the last column of the table I have calculated the actual sizes of the stars compared with α_2 Centauri, assuming that their surfaces are all just as bright as that of α_2 Centauri; which again is not a justifiable assumption, but we may venture to make it for the sake of illustration, and in order to bring out the next point. You will see that some are very big and some very small; they vary in size at least as much as dolls, I think. I never saw a doll more than four or five feet high—say fifty inches; and I never saw one less than about half-an-inch; so that the biggest would be about 100 times the smallest. We may fairly say that Canopus must be at least 100 times the size of α_2 Centauri.

Before we go further, let us think for a moment how astonishing it is that light should reach us from those vast distances at all. If the stars sent out light in only one direction as a searchlight does, we could understand it better; the rays of a search-

light are nearly parallel and in consequence they can go a long distance without failing in brightness. Let us make the lantern send us a parallel beam of light like that of a searchlight : you can see that it does not alter much in cross-section from the lens right away to the wall; and if the rays were *strictly* parallel, it could go across a million or a billion miles without being diminished in brightness. But the light of a star does not behave like this : it spreads out in all directions continually, like the light from this other beam (see Fig. 88), getting, therefore, all the time fainter. On leaving the lantern it spreads out continually as wide as we like, if only we go far enough. That is how the light of a star behaves, and accordingly it gets fainter and fainter the farther it goes. You can see this very easily : we let both the beams fall on the same screen, and when we put the screen near the two lanterns we can make the two patches of about equal brightness. Now they are about of equal brightness. But now if we move the screen away, the patch from the parallel beam remains about the same, while the other gets fainter and fainter. Let us stop here a moment; and now we will put a dark glass in front of the parallel beam lantern, so that its patch is made as faint as the other once more. Again move the screen further off, and the spreading beam again gets fainter. If we bring the screen back towards the lanterns, the spreading beam recovers its brightness, and finally it ends by being brighter than the other. So in spreading out in that way the light of a star is always losing itself; and it is wonderful that it should get to us across those vast distances without being so faint that we cannot really see it at all. The

light even of some of the brightest stars must travel hundreds of years before we can see it. And we have seen that there may be other things which might diminish its light on the way, dark nebulæ which may screen or stop its light. So that it seems wonderful that we should see stars at all. Nevertheless, we do; we get light from even faint stars across long distances; and that shows there cannot

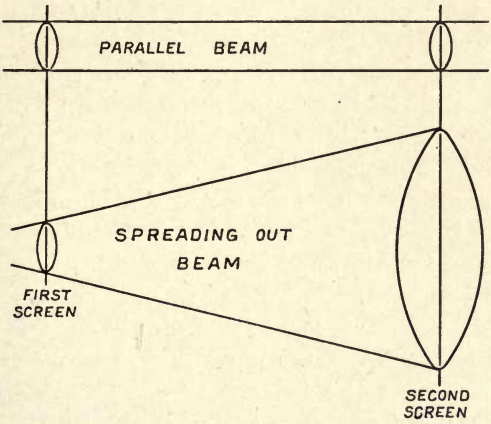


Fig. 88.

be *very much* in the way between us and them. There may be a little very fine "fog," as we might call it; according to our best information to-day there probably *is* a little very fine "fog" between us and the most distant stars; but there cannot be much; otherwise we should not get light and even some heat from the stars. The heat that we get is far harder to detect than the light: it has taxed the utmost resources of physicists at the present day to measure it. Apparatus so delicate that it could

detect the warmth of a young lady's cheek some miles away, failed to record any heat from the stars.

Perhaps you think the heat may get used up on the way because it has to pass through such frightfully cold space. There is no doubt that if we actually took our "Voyage in Space" instead of only pretending, we should be chilled to the marrow very soon indeed. It is terribly cold in space—far colder than we can possibly imagine. You remember the liquid air? Well, cold as that is, it is hot compared with the cold of space. And yet the heat does not get lost in passing through this cold any more than light in passing through simple darkness. If there is anything to *stop* the light—anything material, such as a dark nebula, however flimsy—that is another story; *then* light would be lost. But if there is nothing of that kind in the way the light can go on for hundreds and thousands of years, and so also can heat. Let me show you rather a pretty experiment. Here is a flask of liquid air—very cold, as you know already. We can pass a beam of light and heat from the lantern through it so that the liquid air will not only transmit the heat, but will focus it like a "burning glass," so that we can set a piece of paper alight. There, you see, the paper is on fire! That is because the liquid air, cold as it is, and the flask containing it, are transparent to heat; and similarly space, cold as it is, is transparent to heat, so that we get the heat of the stars across these immense distances, and though the early experiments to detect it failed, others were more successful. The heat of some stars has been definitely measured.

Now let us turn to quite a different thing concerning the stars; to an announcement made two

centuries ago by Halley, that great Englishman who first told us a comet would come back, and was so proud that an Englishman should have been the first to predict it. He also made an even greater announcement, namely, that the stars were moving. From the beginnings of intelligence in man up till then it had been believed that the stars were *fixed;* they were *called* "fixed stars," and the name still survives. Yet Halley pointed out that when old observations were compared with those made in his day, one could not but conclude that some stars had actually moved. He chose especially Sirius, Aldebaran and Arcturus, which had moved since the time of Ptolemy more than the Moon's diameter in one direction, while Betelgeuse, the brightest star in Orion, had moved nearly twice that distance in the opposite direction.

> "What shall we say, then?" he wrote. "It is scarce credible that the Antients could be deceived in so plain a matter, three observers confirming each other. Again, these stars being the most conspicuous in Heaven, are in all probability the nearest to the Earth, and if they have any particular motion of their own it is most likely to be perceived in them."

He seems almost apologetic: for he knew how slow people are to accept a new idea, however plain the evidence may be. After so many centuries of believing the stars to be fixed, it was very hard to unhitch the ideas. "Again, these stars being the most conspicuous in Heaven, are in all probability nearest to the Earth." We have already seen that this is not quite true, but it is nearly true, and the

failure from truth is only a detail. The great thing was to realize this wonderful fact for the first time—that the "fixed stars" were moving: and I think Halley might have been even more proud than in the case of his comet that the discovery was made by an Englishman.

> It might have been a Rooshian,
> Or a French, or Turk, or Prooshian.

Mr. W. S. Gilbert has chaffed us about our pride in being Englishmen; but there are some things in which we may justly feel a national pride, and surely one of them is that an Englishman (and I am glad to add an Oxford man, writing from Oxford) first set the "fixed" stars in motion.

A great many important consequences have followed from this discovery of Halley's. In the first place we find that the movements of the stars afford us a much better test than their brightness for judging whether they are near us or far away. If they are very far away their movements will appear very slow: it is because even the nearest star is so far away that no one noticed any movement in them until Halley discovered it. They are really moving very quickly, but owing to the distance they seem to creep ever so slowly. Do you know Tennyson's beautiful verses about the Eagle?—

> He clasps the crag with crooked hands,
> Close to the Sun in lonely lands,
> Ringed with the azure world, he stands.
>
> The wrinkled sea beneath him crawls,
> He watches from his mountain walls,
> And like a thunderbolt he falls.

In the fourth line Tennyson uses both the effects of distance which we have been considering: it reduces the apparent *size* of objects so that big sea waves look like mere "wrinkles," and it reduces the apparent *movement* until the rolling of the billows looks like mere "crawling." So the huge globes of the stars dwindle at their vast distances into mere specks of light; and their terribly rapid movements—perhaps a hundred miles a second—look like mere "crawling," so slow that it wanted the eagle-eye of a Halley to detect them.

Astronomers have followed up the clue thus found; by watching the stars very carefully for a century and more they have measured the rates at which a good many of them are "crawling." Some seem to go very slowly indeed; others more quickly; and Sir David Gill has found that those which seem to move quickly are, generally speaking, near to us. Here is a table of his results—

SIR DAVID GILL'S DISTANCES OF RAPID STARS.

Star's Name.	Brightness compared with a first magnitude star.	Annual Motion.	Parallax or "Squint."	Distance in "Light Years."	Diameter of star compared with α_2 Centauri.
		"	"		
ZC.V^{h}243 . .	1/1000	8·7	0·31	11	1/17
Lacaille 9352	1/250	7·0	0·28	12	1/8
ϵ Indi . . .	1/33	4·7	0·27	12	1/3
o_2 Eridani. .	1/25	4·1	0·17	19	2/3
e Eridani . .	1/21	3·1	0·15	22	1
β Hydri . .	1/6	2·2	0·13	25	2
ζ Tucanae .	1/21	2·0	0·14	24	1
τ Ceti . . .	1/11	2·0	0·31	11	2
Lacaille 2957	1/100	1·7	0·06	55	1

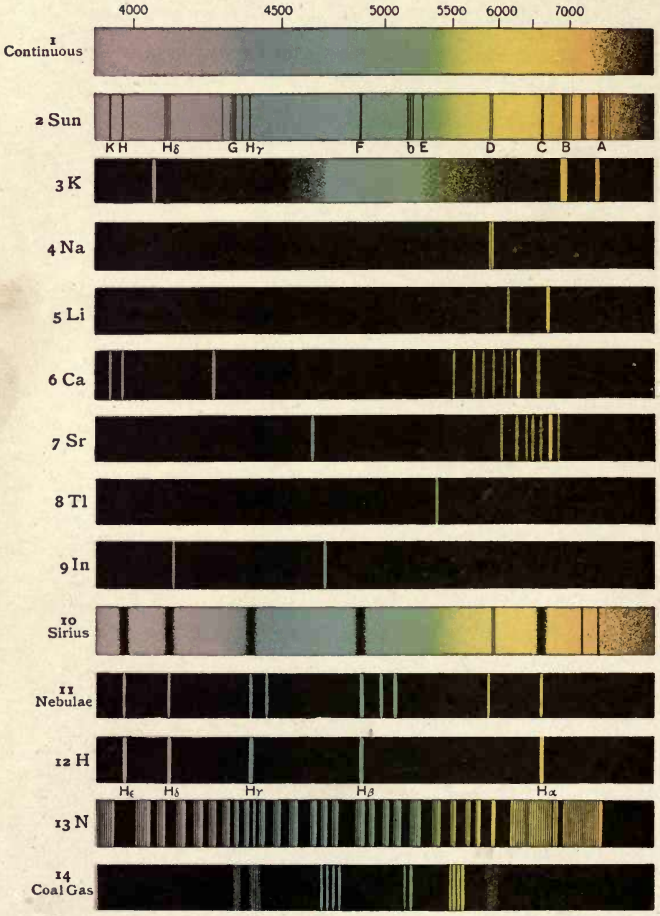
The names in the first column need not concern you further than to notice that they are mostly of a weird kind; clearly these are not familiar stars, but small fry; and the brightness in the second column shows this even more clearly. They are stars which are chiefly of interest to astronomers because of their rapid movements shown in the third column: and you see that they all have measurable "squint" and are within 100 light years of us. The last column shows that they are probably much smaller than the former stars.

The table therefore shows that if a star seems to be moving quickly it is probably nearer us than other stars: if very slowly it is probably far away. But again we must not be too sure in either case, because appearances are often deceptive. Have you ever noticed a train coming nearly straight at you from a long way off? When you are waiting at a station sometimes the lines curl round a corner, so that you do not see the train till it is pretty close; but sometimes they run straight for a long distance and then you can see your train coming from a long way off. It looks no bigger than a toy train, and moreover it seems to be quite still. You know that it is coming towards the station (at least you hope so if it is the train you want to join), but you cannot see it move because it is coming at you *end-on*. It might even be going the opposite way for all you can tell by looking at it. Similarly, if a star seems to us to remain nearly still, we must not be too hasty in thinking that it has very little movement of any kind, and therefore it is very far away, for it may be coming directly at us, or going directly away from us; by merely watching

it we cannot tell. Fortunately, a beautiful method has been discovered by which we can determine whether this is so—whether the star is coming towards us, and how fast it is approaching. Halley showed us how to watch the stars moving across our line of sight, and another great Englishman, Sir William Huggins, showed us how to find out with the spectroscope whether they are coming end-on to us, or moving away from us : and I want now to say something of how he did it.

Let us return to the train for a moment and suppose it whistles as it approaches the station. It will whistle a high note; let us say high D on the piano. Now if the train is coming at us the note will not sound like D, but like a note higher in the scale, say D sharp; if on the contrary it is running away from us, the whistle will sound lower in the scale, say D flat. Sometimes a train rushes right through a station whistling all the time, and then you can notice the change from D sharp to D flat quite easily. Many people have thought that the train changed its whistle as it went through, but that is not the case, it keeps on whistling the same note all the time; but while it is still approaching you hear a higher note; immediately it has passed you and begins to run away you hear the lower note.

You can hear much the same kind of thing with a passing motor-car if it happens to sound its horn. Or without the horn at all, if you listen to the hum of the machinery you will hear it change its note as it passes. If the motor-car is going slow, the change will not be much; but if it is going very fast, the change will be great. It would be quite



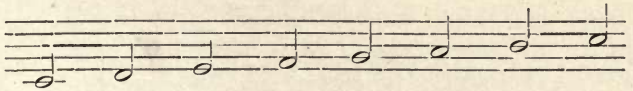
VARIOUS SPECTRA.
(See Notes to Illustrations.)

References to this are on pp. 126, 128, 275.

[*To face p.* 273.

day, but Sunday's loaf was delivered late—say on Tuesday; if all the others were two days late also then you would still get a loaf every day. But if they got less and less late until Saturday's loaf came as soon as it was baked, then you would get a whole week's loaves in the five days. After that we may suppose the delivery begins to get late again until the next Sunday's loaf is once more two days late—seven loaves in nine days, which is like the low note of a train leaving a station.

If this does not seem clear, never mind: you will perhaps find a better explanation some day. But now I want you to think of light instead of sound, because the stars do not whistle to us, but they do send us light. You remember that we were to compare light and sound several times in this lecture? And I want you to realize that just as there are scales in sound, which you have to practise on the piano, so there are scales in light—nothing more nor less than those beautiful colours which a prism makes for us. We will throw one of those rainbow-coloured strips on the screen; and to fix the likeness of colours to scales in your minds I will put this harmonium underneath the strip and play a scale. The low notes in the bass correspond to the red colour, and as we go up the scale we pass through orange, yellow, etc.—all the colours of the rainbow up to violet. You might sing the names to a scale so as to remember this fact.



T

Perhaps you don't know that last colour; it is mainly put in to fill up the scale, which would otherwise stop awkwardly short; it does not mean ultra-marine, but ultra-violet. I don't mean that the colours correspond to these notes in detail, but that in passing from red to violet the pitch rises.

If a star is whistling a green note, that is to say sending us green light, then if it is also coming directly at us the green note will rise in the scale towards the blue; if the star is running away the green note will fall in the scale towards the yellow. How much it rises or falls depends on the rate of movement, and I may say at once that the rise or fall is very slight indeed, because however quick the movement of the star may seem to us, it is very, very slow compared with the enormous velocity of light. But the rise or fall *is* noticeable and measurable; by noticing it and measuring it astronomers have found out which stars are coming at us and which are running away, and how fast they are coming or going.

Some of the best illustrations of this way of measuring velocities, whether by sound or by light, are afforded by bodies which are whirling or turning round, because sometimes they approach, sometimes they recede. Here is an instrument called a "bull-roarer" which some of you may have made for yourselves—a shaped piece of wood with a string tied to it. If I whirl it round it makes a humming noise. Now I can whirl it round so that it remains always at the same distance from you, and then the hum is steady; but if I turn end-on to you, sometimes it approaches and sometimes

it recedes, and you can hear the note change up and down.

Similarly, if one star is whirling round another, it may do so in such a way as to remain nearly at the same distance from us, when its light remains of uniform colour; but the orbit may also be end-on to us, when we see the colours go up and down. I am using the word colour in a special sense: when we spread out the light of a star into colours by a spectroscope, we see the band crossed by a number of dark lines which mean special colours: and it is these lines which are displaced towards the violet or towards the red (see Plate facing p. 273). And now we will look at a very beautiful instance of this displacement in the case of the planet Saturn and its ring.

Let us first consider the planet himself or the "ball," as it is usually called to distinguish it from the "ring." Suppose we have cut a slice right through the centre O; the slice will be turning round O (Fig. 89). The left side A is coming at us and the right side B is running away; so that if we pass the light of this slice through a spectroscope, one end of the colour-line will be displaced one way and the other the other, in consequence of which we get a sloped line XY instead of a horizontal one PQ. Next, if the ring were solid and attached to the ball, the same state of things would continue in the ring; the line XY would be merely extended to HK. But the ring is *not* solid, as we have seen: it is made up of little satellites, the outer ones moving, not *faster* than the inner ones, as they would if the ring were solid, but

slower than the inner ones. Hence the ends of the line, instead of being more displaced, are less displaced, and we get an elongated Z shape VXYW. This was predicted from knowledge of the movements, and when the spectroscope was actually turned on to Saturn the prediction was beautifully verified! So that we may feel all confidence in the power of the spectroscope to tell us about these movements of approach and recession.

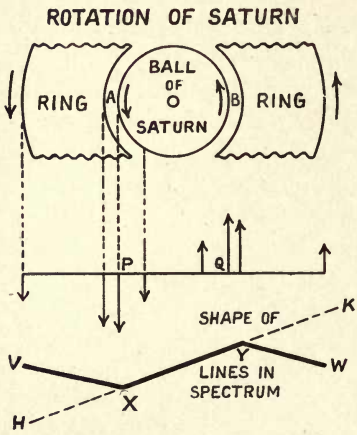


Fig. 89.

We have, then, two different ways of measuring the movements of the stars; it is a piece of great good luck for us that we have two, for we can often test what one method has told us by using the other. And now I want to tell you some of the things we have found out by watching the movements of the stars in these two ways.

First of all let us pay a few visits to the double stars—cases where two stars are seen close together, and where careful watching has shown that they are revolving round each other. Sometimes one is so much the larger that we may almost say that the smaller is revolving round it, like our Earth round the Sun; but there are other cases when the stars

are so nearly equal in size that we cannot give one the preference in this way; and in all cases it is more correct to regard both stars as revolving round some point in between them than to regard one as fixed and the other as revolving round it.

These double stars are often beautifully coloured; one of them being of a different colour from the other. But our chief concern to-day is not with the colours, but with the movements of the two partners. They are waltzing round one another just like a pair of dancers in a ballroom: the idea of waltzing will help us very much, because the dancers not only turn round one another but move down the room at the same time. At the corners of the room they have to turn, and it is possible that our waltzing double stars may have to turn at some corner or other in the future: at present we cannot say because we have not been watching them waltz long enough; we have only had about a century to watch them since they were discovered, and even a century is but a short time in the life of a double star. Some of them take as long as that to make a single waltz-turn, and others take much longer—so much longer that in the century since they have been watched they have scarcely turned at all. You may ask how we know that they are partners in that case. Well, sometimes you see a pair of partners in a ballroom not waltzing round at all, but going down the room without turning. We know that they are partners because they keep together as they move down the room; and so it is with these double stars which do not seem to be turning—they are nevertheless moving together

among the other stars hand-in-hand so to speak; so that we may safely regard them as partners. Thus a ballroom helps us in several ways to think of the movements of the stars, but now I come to a point where it ceases to help us. Partners in a ballroom are always in pairs; I *have* seen three people waltzing together for fun, but you would not see it often; and I doubt whether you would ever see four or five together, let alone twenty or thirty. But with the stars it is different. The general rule is for a pair of stars to waltz together, but we often have three or four, and lately we have been finding groups of thirty or forty together, or even more. We detect the partnership because they move together in the ballroom: when there are only three or four, we can sometimes see them also turning round one another, but the movements are apt to be complicated when there are more than two, because it is difficult to know which of the several partners you are to pay attention to at any one time. All the partners in the group are pulling at one another, and though we know the exact law of the pulls (which is simply that great Law of Gravitation which Newton found out for us), it is quite impossible for mathematicians, with all their present skill, to trace out the consequences of the law. Perhaps they may have better success in the future, but meantime we need not trouble so much about the treatment of one partner or another because what I want you to notice chiefly is that *the whole group moves together.* Look (Fig. 90) at the picture of the group called the Pleiades, in which arrows are drawn to represent

the movements of the separate stars in a given time: you will see that many of these arrows are *about* in the same direction and *about* of the same length. The stars are shown as round black dots (as they would be on a photographic negative) in their present positions, and the arrow-heads show where they will get to after thousands of years.

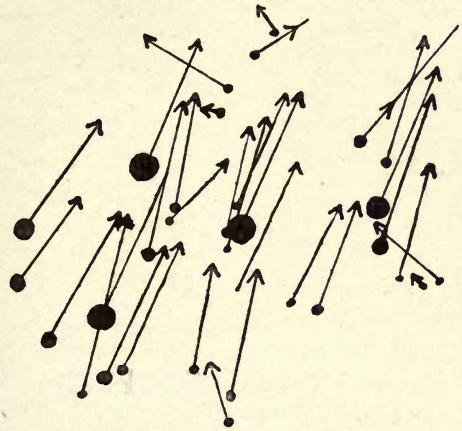


Fig. 90.—Movements of the Pleiades.

Since the arrows are not *quite* equal in length, and *quite* the same in direction, the arrow-heads form a figure rather different from the arrow-tails: that is to say, after this lapse of time the partners will have taken up rather different positions. They have felt the pulls of gravitation and responded to them—at any rate this is a reasonable explanation. They are waltzing to a certain extent, but not enough to prevent them all keeping together and moving down the room as a group of partners.

This noticeable fact about the Pleiades is not very new. The late Mr. R. A. Proctor called attention to it forty or fifty years ago. But another group of stars in the constellation of the Bull was only noticed quite lately, by Mr. Lewis Boss, a great American astronomer. The movements of these stars are so slow—such a snail's "crawl"—that it required very great care and skill to measure

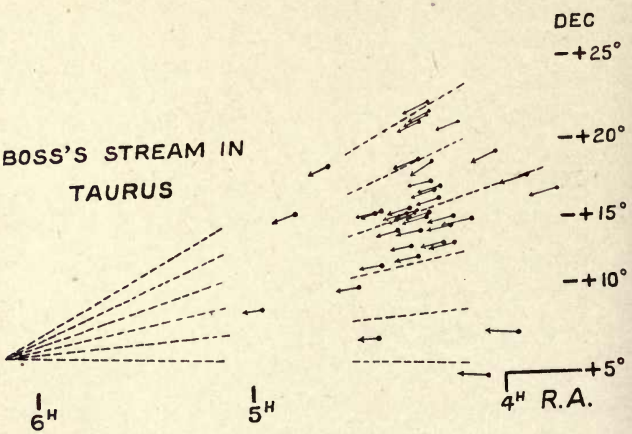


Fig. 91.

them. The main point about the arrows in Fig. 91 (which again represent the movements in a given time—about 50,000 years) is that they are not parallel to each other, but would meet in a point if carried far enough. It looks as though the stars would collide with one another at some time in the future, but that need not be the case. If you stand on the railway, where the lines run straight they will seem to meet in the distance, whereas we know that they always remain the same distance

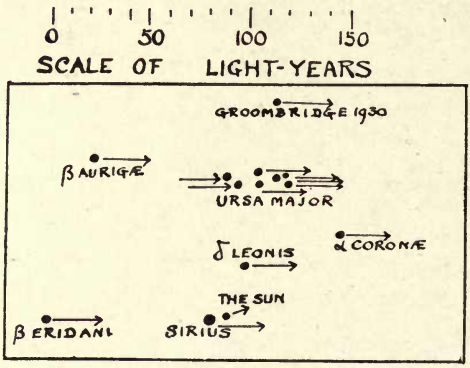
apart. The apparent meeting is an effect of "perspective." Some of you have no doubt learnt perspective drawing and you know that parallel lines have to be drawn to meet in a "vanishing point." So Mr. Boss's group of stars may be moving along parallel lines, without closing up: and indeed we can find out that this is the fact,

Fig. 92.
(See Notes to Illustrations.)

by using the second method of watching their movements which we noticed, with the spectroscope. The "vanishing point" represents the direction in the far distance to which they are migrating, like a flock of birds such as we see in Fig. 92.

There is one more group which I should like you to know of, part of which was also identified long ago by Mr. Proctor. He pointed out that if we

omit the first and last stars in the Great Bear or Dipper, the five remaining in the middle form a group flying along together. But it has recently been discovered that several other stars belong to this group, notably Sirius the Dog-star. Now I hope you know where to look for Sirius—away in the south. We in Europe never see him very far



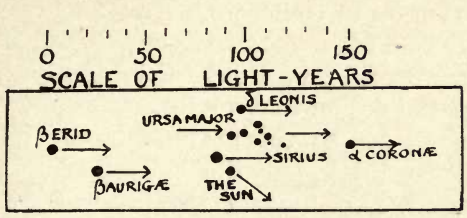
THE SIRIUS–URSA MAJOR CLUSTER

SEEN IN PLAN

Fig. 93.

away from the south : and, as you know, the Great Bear is in the north. Does it not seem strange that Sirius in the south should belong to the same group of stars as the five Great Bear stars in the north? The group is like a flock of birds flying just over our heads, some of which have passed us while others have not yet come up. There seems to be no doubt about the association of these stars, for their movements have been tested in

both the ways we described; and besides that, the distances of some of them (especially Sirius) have been measured; and all the facts fit in well together, so that we can actually make a model of this system of stars. Miss Bellamy has kindly made one for us by sticking hatpins into this cork mat: and please notice how very *flat* it is. The pinheads are *nearly* all at the same height from the mat—not quite the same, but nearly enough to be note-



THE SIRIUS–URSA MAJOR CLUSTER

SEEN EDGEWISE

Fig. 94.

worthy. We may almost compare this group of stars to a fleet of ships sailing on the flat ocean: but the fleet is of a stupendous size—its length is about 150 light years; that is to say that if the admiral on the leading ship signalled to his fleet, it would be 150 years before the last ship would even see the signal! How long it would take us to go round and pay a visit to each ship in turn you can perhaps imagine for yourselves.

We have now noticed three groups of stars and found that, though they may be altering their places a little in the group, each group is never-

theless steadily moving in a particular direction—making a sort of migration. Whence did they come and whither are they going? Will they go on for ever or will they come back after a time as migrating birds do? These are questions which suggest themselves at once, though they are not so easily answered. I think, however, that an answer can be given: an answer which suggests itself if we go back to that notion of our belonging to a large cluster of stars to which we were led earlier in the lecture. You remember that our "audience" of stars, as we called it, thins off in the back rows, giving us the notion that we form part of a definite cluster such as we see in the picture (Fig. 85). Now let us think out the consequences of this arrangement, remembering that by the great Law of Gravitation each star is pulling every other star. We have already said that even with three or four stars it is so difficult to tell what will happen in detail that the best mathematicians have not yet been able to work it out: so you may think that with millions and millions of stars it would be quite hopeless. But curiously enough it makes the problem in some ways simpler to have a very large number, and I do not think we shall find it very hard to think out some of the consequences. For instance, it is easy to see that a star right in the middle of the bunch will be pulled in all directions at once—to right as well as to left, up as much as down—so that it will not know which way to move; and if it had already no movement it would not acquire any. But it would be very different for a star on the boundary: all the pulls would be

on one side, namely, more or less towards the centre of the bunch. Some stars would pull it rather to one side of the centre, others rather to the other side: but there would be no stars at all to pull it *away* from the centre, and hence it would know very definitely in which direction to move, namely towards the centre. Let us go with it in its journey and see what happens. After a little time it would be no longer quite on the boundary, but would have penetrated a little way into the bunch. There would now be a few stars pulling it away from the centre, but only very few compared with those urging it on; it would still be urged centrewards and would quicken its pace: and without troubling about the details you will see that this sort of thing would go on until the star arrived at the centre, when there would be no force on it either way, as we said before. But that does not mean that it would stop, for it has got "way on." Let us look for a moment at this pendulum. When I let it hang vertically it is like a star at rest in the middle of the bunch; there is nothing to make it move. But if I pull it to one side it is like our star on the outside of the bunch—it is being pulled towards the centre, and if I let it go it swings thither. But on arriving at the centre it does not stop, because, although there is no force moving it forwards, it has got "way on" and so passes through. Directly it has passed through, the force begins to call it back, but it cannot stop it all at once—the pendulum swings out to the other side before returning. So with our star which we started from the outside of the bunch or cluster: it will arrive at the centre,

pass through it, and swing out to the other side. Then it would come back again as the pendulum does; and that is what I think the stars are doing in our great cluster, some of them moving alone, some in pairs (the double stars) and others in groups; but all swinging to and fro through the centre of the whole bunch.

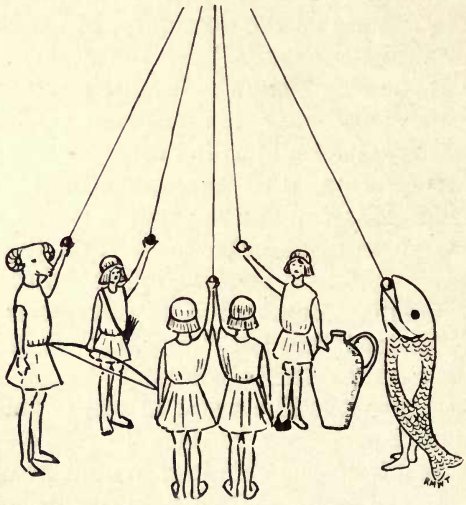


Fig. 95.—The experiment with the billiard balls, idealized by a member of the audience.

But now how is it that they keep clear of one another? If I take, instead of a single pendulum as before, a whole lot of pendulums all swinging through the same centre, they will be liable to strike one another. Let us try the experiment. Here we have several billiard balls hung by long strings to the theatre roof, and we will see how

much they hit. Indeed, we will try to make them hit. If several of my young friends will each hold one ball in different directions, and then all let go at exactly the same moment I think we shall get a good crash at the centre when they meet: but if they do not let go at *exactly* the same moment, then they will miss.[1] Now are you all ready to let go when I say "three"? Don't fling the balls at all, just open your fingers and let them drop. One, two, THREE!

Some of them hit, you see, but one or two missed: and now you see that after a few turns they seem to avoid one another very cleverly partly because some of them have been knocked a little sideways and do not pass accurately through the centre, and partly because some arrive there at one time and some at another: so that though they are all still oscillating through the centre in a general kind of way, collisions are comparatively rare.

I think the stars in our cluster are moving somewhat in this way—oscillating to and fro through the centre—and I have tried to represent the movements very crudely by means of the kinematograph.

[Exhibition here of the results with kinematograph. The opportunity was taken to show also some features of a total solar eclipse; such as fowls going in to roost during the darkness and coming out afterwards.]

I think there are occasional collisions, which perhaps make what we call "new stars": and in

[1] A fanciful representation of this little experiment is shown in Fig. 95.

times gone by these collisions may have been more serious and more frequent. But I do not want to trouble you about the collisions so much as the general movements to and fro. That very phrase "to and fro" reminds us of one most important feature of the movements, namely that they are sometimes "to" the centre and sometimes "fro" or from it. At any given moment, therefore, we can divide the stars into two lots, one lot going *to* the centre and the other lot coming *from* it. Let us think of the first lot alone. If we watch their movements and represent them by arrows, then all these arrows will point to the centre: they will converge towards a point just like the arrows in the picture of Mr. Boss's cluster (Fig. 91). Now, in the case of this cluster, we said that the stars were not really moving towards a point, but in parallel lines: we knew that because we had the second method of watching the velocities to help the first. But if we had not had that second method to help us, we could not really have told whether the movement was in parallel lines or to a point: the perspective appearance would be just the same. And we might easily make a mistake in concluding, when we see arrows representing star movements directed to a point, that the movements are really parallel. They may really be to a point. Lots of boys christened Henry are called Harry "for short," but you might easily make a mistake if you concluded that every Harry had been really christened Henry, for some of them are christened Harry direct. And I think that astronomers are liable to make just this very mistake about the

star movements. They see one lot going to the centre of the system and another lot coming away: and they have argued that since the first lot seem to be converging to a point their movements are really parallel. They *might* be parallel just as Harry's real name might be Henry; but they also may be actually moving towards a point as they seem to be, just as Harry's name may be really Harry outright. And when there is a very good reason why they *should* be moving to a point, because all the stars belonging to the system are all being pulled towards the centre, as we know, then it seems better to take that as the explanation rather than go out of our way to treat the movements as parallel. The same may be said of the outgoing stream: their arrows seem to *diverge from* a point, and they *might* be merely a perspective appearance of movements that were really parallel; but it might also be true that the stars are moving outwards from the centre (like the pendulum that passes through the centre because it has got way on), and when there is a good reason for the latter alternative it seems sensible to adopt it.

In mentioning this great fact, that we can divide the stars into two lots, one going one way and one going the other, I have omitted several very important things so as to keep the argument simple. One important thing is who first found it out. It was first announced by Professor Kapteyn of Groningen in 1904, not yet ten years ago: and it reflects the very greatest credit upon him that he made the discovery. Many other people have confirmed it since, and the evidence is so clear that

now it seems wonderful that it should have been overlooked so long. That is often the case in science: once the way is shown, it is easy enough to follow it; but it may require a genius to show the way in the first instance. Have you ever hunted for seabirds' eggs on the shore? They are so nearly the colour of the stones that it takes a very sharp eye to find them, though when once they are pointed out they are easily seen.

Another thing is that the arrows of the star movements do not converge *accurately* to a point: indeed many of them are wildly wrong. That is what made the great discovery so difficult. It is only by taking careful averages of hundreds of stars that the general tendencies were discovered. This means that, although there is on the whole a tendency to the centre of our cluster, many of the stars have had knocks which carry them to one side or the other, just as our billiard balls had after the first few swings. There is no difficulty in this, however; indeed, it removes a difficulty that might have otherwise existed, for it shows how too-frequent collisions are avoided by the stars passing to one side or other of the centre. Some of them, indeed, may never go near the centre at all; they may whirl round and round it just as I can make this pendulum-bob whirl round and round instead of oscillating to and fro. To make it describe a circle I need only give it enough sideways motion, and now you see it never goes near the centre. But if all the stars moved like this, there would be none near the centre, except some almost stationary, as the pendulum is now. There

must be a certain number, at any rate, which swing backwards and forwards through the centre, and though these are mixed with others which swing wide, there is still enough oscillation to enable Professor Kapteyn to make his great discovery. I must not, however, mislead you into thinking that he agrees with my interpretation of it, for he does not. He prefers to regard the movements as parallel.

There is another point to be noticed about the stars which circle round the centre of the cluster instead of passing to and fro through it or near it. They remain at a distance from the centre, possibly at a great distance; if so they may form a separate ring round the central cluster. This might explain the Milky Way, that beautiful soft track of light which you can see crossing the sky when there is not too much moonlight. It makes a complete ring round us, though we cannot realize that without going into the southern hemisphere as well as the northern: and when we look at it through a powerful telescope, or take photographs of it, we find that it is dotted over with thousands and thousands of stars. Perhaps it is a ring of the stars which always keep far away from the centre, but as yet we cannot tell, because we have not sufficient knowledge of the movements of these stars. To measure the movement of a star we must record its position carefully at some selected time, then wait a number of years and note how far it has changed. If the star is far away, the change will be very slow and we must wait proportionately longer in order to detect it. For the stars near us a few years may suffice: there are one or two

stars moving so rapidly that we can see their change of position in a week—almost in a day; but such cases are quite exceptional, and we may go much further and say that it is quite exceptional to find a star which has moved appreciably even after ten years. We have spent a great deal of time at Oxford lately in looking for such changes, by comparing photographs of the same region in the sky taken at intervals of at least ten years, and out of the hundreds of stars on the plates we only find one or two which have moved appreciably in ten years. Moreover, we find about the same number on a plate whether the region represented be in the Milky Way or far from it. In the former case there may be one thousand stars shown on the plate: in the latter case only one hundred: and yet we are just as likely to find two stars which have moved appreciably in the latter case as in the former. The inference seems to be that the extra 900 stars are all too far away to show the slightest motion in ten years: we must wait fifty or one hundred years to see them move. If any one had photographed them fifty or one hundred years ago, we might to-day have known something of their movements; but unfortunately astronomers had not learnt how to photograph faint stars at that time; they began only twenty or thirty years ago.

It is time that we said a word as to the position of our own Earth in all this organized movement. Our Earth and all the other planets and satellites must be regarded as being carried along with the Sun. Compared with the distances of the stars our distance from the Sun is really very small,

You remember how we said in the last lecture that it takes us only eight minutes to get to the Sun on the wings of light, whereas it takes years to get to the nearest star. Another way to think of it is this: suppose our path round the Sun were represented by a wedding-ring, then on the same scale the nearest star would be some miles away. Hence we can regard all the planets and satellites as a tiny little bunch travelling with the Sun, and we can talk of the Sun alone as travelling, carrying us with him in his pocket so to speak. Now how is our Sun behaving in this matter of migrations? Is he one of the stars that pass to and fro through the centre, or does he remain at a distance from it? The answer seems to be, from the best evidence we can get at the moment, that he travels to and fro, and at the present moment he has just been through or near the centre—only about a million years ago. Perhaps you think that is so long ago that we must by this time have come very far away; but a million years is probably only a small fraction of the time for a whole swing, which may be estimated roughly at about 200 million years. And that brings us back to that little table which we made at the beginning of the lecture; we had to leave it incomplete, but now we can complete it.

30 million light vibrations make one wireless vibration.
30 million wireless vibrations make one second.
30 million seconds make one year.
30 million years make one "migration."

I have now put 30 million years for a migration

instead of 200, firstly to make the table simpler by having all the figures the same, and secondly to remind us that when I said 200 millions just now it was little more than a guess. It was the best guess I could make, but it may be wildly wrong; perhaps 30 million will do just as well, and it has the advantage of making our table simple.

We on our Earth, then, are accompanying the Sun in these migrations—we are all making this great VOYAGE IN SPACE, not metaphorically by telescope, but actually and in reality. We are doing it in a leisurely manner, perhaps you will think, seeing that it takes so many million years to make even one " migration " : we cannot, even the youngest of us, hope to see the end of a turn, or even to see the scenery change much : it takes us all our time and attention to detect that we are moving at all. Have you read how Mark Twain once boarded a glacier to travel downhill? He had learnt that a glacier was really a moving river of ice, and solemnly pretended to use it for a journey, and to be astonished and bitterly disappointed when he learnt that it would take years to go a few yards. I hope you will not form any similar expectations about our journey. We are certainly making it, but as regards change of scenery in our short lives it is slower even than a glacier.

And I have used the word " migration " to denote the time taken by the Sun to swing from one end of its tether to the other. It seems possible that all of the stars in our cluster take about the same time to make their " migrations," just as the billiard balls did when hung by strings of the same

ength. It is not at all likely that the " migrations " are *accurately* in the same time : all I mean is that they may not differ so much as the periods of our planets, for instance, the innermost of which (Mercury) takes only eighty-eight days to go round the Sun, while the outermost (Neptune) takes 160 years. It would take too long to explain the reason for and against the " migrations " being all nearly equal in point of time : perhaps you will allow me to state it without further explanation. And now let me add that this does not mean that the swings are of the same length as regards distance. We can pull a pendulum far out from its position of rest, and then when we let it go it makes a big swing : or we can pull it out only a little way and then its swing will be small; but the *time* of swing will remain the same. This was Galileo's great discovery about the pendulum. In the same way I fancy there are stars with big swings and stars which take only little swings and so never get far from the centre. On the whole the big bright stars will swing out farthest, and the little faint ones will swing quietly; but all much in the same time.

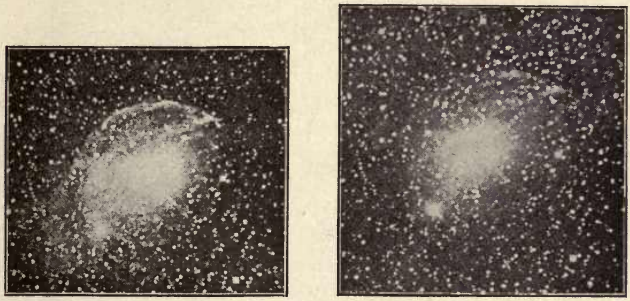
The question arises whether there is likely to be a collision occasionally between the stars migrating in opposite directions. This would doubtless make a considerable " flare-up," and it is tempting to suppose that the " new stars " which we see suddenly appear in the sky represent a collision of this kind. The chief difficulty is that stars are so small compared with the enormous distances between them that a collision between two must be extremely

rare. What seems to me much more likely is that a star may collide with a dark nebula such as we concluded must exist in order to account for the patches empty of stars. To take an illustration from a well-known game, it is extremely unlikely that two golf balls will hit one another in mid-air, though on links like those of St. Andrews they may be struck off in opposite directions. I believe such a collision has happened, but thousands and thousands of balls must have passed more or less near one another without hitting. On the other hand it is pretty easy for a golf ball to hit a furze bush, as all golfers know. Now I think these dark nebulæ are like the furze bushes and bunkers on a golf course, which almost seem sometimes to attract the ball out of perversity. Up till a few years ago such an idea would have been mere speculation: but in 1901 we had a splendid "new star" which gave us direct evidence of such an occurrence. Nova Persei, the "new star of the new century," blazed up suddenly, and died down slowly like all "new" stars: but after it had become faint again, a photograph of it showed a nebula surrounding it: and by comparing photographs the nebula was seen to be changing its shape (Fig. 96). At first it was thought that there had been an explosion of some kind and the nebula represented the scattering fragments; but it was presently realized that the rate of scattering was far too great for this explanation; and ultimately the startling truth was realized that we were witnessing some of those light "echoes" to which I referred at the beginning of the lecture. Let us

think of actual echoes first. Suppose I repeat Tennyson's lines from the "Charge of the Light Brigade" in an even voice thus—

> Came through the jaws of Death,
> Back from the mouth of Hell,
> All that was left of them.

We might take that to represent the light of a star shining steadily, because I said the words in



September 20, 1901. November 13, 1901.

Fig. 96.—The expansion of the nebulous appearance about Nova Persei.

an even monotonous way. But now let me say them to represent the way a new star blazes up suddenly—

> Came through the jaws of Death,
> BACK from the mouth of Hell,
> All that was left of them,
> Left of six hundred.

You see I began faint and steady, because there seems to be generally a faint steady star which blazes out into a new one: then suddenly I mounted

up to the word "BACK," which represents the fiercest outblaze, and then gradually down again to faintness.

Now suppose when my voice had become faint again we were to hear the word "Back," "Back," "Back," repeated several times: we should say at once that those were the echoes of my biggest shout from some distant hills or buildings. And that is what probably happened with light echoes in the case of Nova Persei. A fair explanation seems to be that a faint star in its travels came across a dark nebula, one of the "bunkers" of space; and thereupon blazed up. The blaze lit up the previously dark nebula or bunker for us to see; but as light takes time to travel, it was not until some months after the flare-up that we got the light echoes from the nebula. We identify the illumination as an echo much as we could identify the sound echo: the word "Back" was repeated, not "mouth" or "hell," and this is reasonable because "Back" was the loudest word. Similarly the light of the echo, when analysed with the spectroscope, was found to correspond with the light of the greatest flare-up: the chain of evidence is complete. There is just one alternative supposition in detail which I will mention, but cannot dwell upon. It is possible that the big "flare-up" was caused, not by the entry of a wandering star into the nebula, but by the contraction of a part of the nebula under its own gravitation. The rest of the explanation would then follow as before.

But now I have tried your patience quite enough. Our visits to the stars have been rather more

arduous than those which have gone before; just as visits to very distant acquaintances are apt to be more tedious than family parties. You have, however, listened very patiently, and I offer you my best thanks and best wishes for a Happy New Year.

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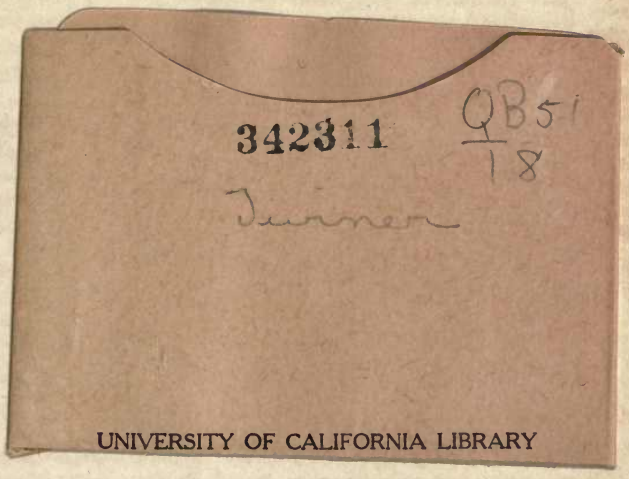
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